CHAPTER 5

FUNDAMENTALS OF EMC/RADHAZ

5.1 BASIC EMC CONSIDERATIONS

In analyzing the EMC effects of an installation there are many potential sources of interference; these are discussed in subsequent paragraphs to assist in the EMC analysis.

Any circuit, device or equipment carrying an electric current must be thought of as a potential source, or receptor of emissions. Figure 5-1 shows the three basic components of an interference situation; the interference source or generator of the undesired signal, the transfer medium or coupling mechanism, and the receiving element or susceptible device exhibiting the undesired response.

Compatibility is achieved by: minimizing the generation of potential interference emission at the source, minimizing the transferred signal by isolation, shielding, and other techniques, designing the receiving element to be non-susceptible to the emission; or combinations of the preceding.

5.1.1 Interference Generation

Interference-causing signals are associated with time-varying electrical or magnetic fields directly related to rates of change of currents with time. A source producing current changes generates either periodic signals, impulse signals, or a signal which varies randomly with time.

Generally, interference-causing signals may be grouped into two categories, narrowband or broadband (random and impulse).

Typical sources of random signals are fluorescent lamps, thermal noise, and atmospheric noise; typical sources of impulse signals are switches, ignition devices, and power lines.

Pulsed signals represent one of the most common sources of EMI. The more rapid and abrupt the rise and fall of the pulse, the greater the likelihood the interference will be generated over a broader frequency spectrum.

Random and impulse type signals are similar, in that they are distinguished by the partial or completely overlapping nature of the random signals versus the distinct individual pulses characterizing impulse noise.

As mentioned previously, potential interference signals may also be periodic in nature. Periodic signals are characterized by a systematic or cyclic repetition of the amplitude variation with time. Typical sources are oscillators, communications transmitters, and radar transmitters. Although all potentially interfering signals can most obviously be thought of as functions of amplitude versus time, each can also be equivalently thought of as a function of amplitude versus frequency. Often attenuation and other propagation phenomena between the interference source and victim device are different for different frequency components of the interference signal. Most significantly, the response of many devices to interfering energy is a function of frequency.

5.1.2 Interference Sources

Interference sources may be classified into two broad categories: natural and manmade. The latter can be subdivided into functional sources and incidental sources.

Functional sources of interference refer to equipments having the intentional generation of a useful signal as their prime function. Communication and radar transmitters, oscillators, and signal generators are examples.

All radar and communications transmitters, radionavigational systems beacons, etc., intentionally radiate signals for the purpose of conveying information. These signals are potential major sources of interference to receiving devices in the electromagnetic environment. There are three major types of potentially interfering signals from functional sources: intentionally radiated signals, harmonically related spurious emissions and non-harmonically related spurious emissions.

a. Functional Sources. A typical example is transmitter-generated signals. Several basic sources of spurious frequencies exist within a transmitter. These basic sources emit spurious radiation that can be divided into:

o Harmonics of the transmitter fundamental (f_o).

o Harmonics of the transmitter master oscillator frequency (f_{mo}). These outputs will occur between harmonics of f_o for those transmitters having a master oscillator frequency below the fundamental frequency.

o Nonharmonically-related outputs (for example, those that occur in a magnetron).

o Noise.

Although each of the listed types of spurious radiation exists, it can be stated that in all except high-power transmitters, the noise level is generally not significant relative to the other three types.

In the first two types of spurious radiation (the harmonically-related spurious), these signals are primarily generated from oscillator and multiplier stages of the transmitter, from power amplifiers, and from mixer or frequency synthesizing stages of the transmitters.

In some transmitter systems, a mixer is used to generate the system fundamental output frequency or a submultiple thereof. When this is the case, spurious emissions are generated in the mixer. To illustrate what specific frequencies are generated, consider as an example the generation of a transmitter fundamental frequency in a transmitter-receiver system which uses the local oscillator in both the transmitter and receiver sections. If the fundamental output from the transmitter is ($f_1 + f_{LO}$), where f_{LO} is the local oscillator frequency and f_1 is a crystal oscillator frequency, then signals are generated at ($f_1 - f_{LO}$), ($2f_1 + f_{LO}$), ($f_1 + 2f_{LO}$), etc. due to the nonlinearities of the mixer. From this example, it can be seen that many spurious signals are generated and, hence, tuned circuits are required following the mixer stage in order to attenuate the undesired frequencies. For most equipments, these spurious or harmonic signals must be investigated and attenuated if found to cause interference.

Harmonically-related spurious emissions generated by the methods just described, along with high-power fundamental frequencies of any nearby transmitters, can generate adjacent and co-channel interference in receiving systems. Usually, direct co-channel signals (without intermodulation or mixing occurring) can be traced to spurious emissions, rather than from the fundamental of a distant transmitter, since frequency allocation plans usually prohibit co-channel operation unless the channels are on a time-sharing plan.

It should be pointed out that when discussing spurious emissions, in the form of harmonics of the transmitter, the receiving devices to be considered include intentional receivers of electromagnetic energy as well as other devices that are susceptible to the effects of electromagnetic radiations.

Basically, nonharmonically-related spurious emissions are generated primarily from high-power oscillator sources such as magnetrons used in radar transmitting systems.

b. Incidental Sources. This type of interference is associated with all equipments or devices which do not generate a useful signal as their prime function. Some of the more important sources include:

o Switching devices

o Ignition systems

o Rectifiers and regulators

- o Brush and commutator type electrical machinery
- o Power lines
- o Fluorescent and other gas filled lamps
- o Welding devices
- o Industrial equipment, e.g., RF heaters
- o Arcing and corona.

A brief discussion of the interference characteristics of some of these devices follows.

(1) Switches. All switches cause essentially the same types of interference whether electrical, thermostatic, electromechanical or electronic in operation. The switch is essentially a device that can abruptly change its electrical impedance from zero to infinity or from infinity to zero. This sudden change causes current and voltage transients throughout the circuit resulting in generation of broadband emissions which may cause interference. In the case of manually actuated electrical switches, the emission produced is generally of relatively short duration unless there are capacitors or inductors in the circuit. Usually such emission is not repetitive or if it is, repetition is at a slow or irregular rate. Switching interference is more severe when large current values are involved because arcing across switch contacts when making or breaking circuits greatly intensifies the interference in both level and duration.

Electromechanically actuated switches such as relays, vibrators, and buzzers create exactly the same type of broadband emissions as do manually actuated switches, but usually at a faster rate. Repetitive interrupters, such as vibrators, produce the same broad spectrum emission on a continual basis.

Thyratrons and similar gaseous discharge tubes are frequently utilized for switching purposes because of their extremely fast operating time. Because of this fast operating time, however, such tubes create very substantial amounts of interference, particularly when handling large currents. Thyratrons having turn-on times in the order of 1 μ sec are quite common. Just as with manual switches, thyratrons being operated infrequently can cause considerable broadband interference, though only for a relatively short time duration. Thyratrons, when discharged repetitiously at a high rate, such as when used for the control of motors and other equipment, can create very intense broadband interference on a continuous basis.

Silicon-controlled rectifiers are related to the transistor in much the same manner as the thyratron is related to the triode. These devices are capable of handling substantial amounts of power and are either nonconductive or conductive, depending upon their bias. When triggered, the controlled rectifier reaches its maximum state of conductivity very rapidly. The result is the production of a wide band of electromagnetic interference. Because controlled rectifiers are often used as repetitious switching devices in static inverters and power converters, they can be a continuous source of broadband interference.

(2) Ignition Systems. Ignition systems are strong producers of EMI characterized by high-amplitude, short-duration pulses which exhibit broadband properties. The sources within an ignition system known to produce interference signals are the breaker points, spark-plug wiring, distributor, generator and voltage regulator. These signals can generally be regarded as being of the impulse type.

Figure 5-2 shows a typical spark-plug voltage waveform from an automobile ignition system. Illustrated are the points along the wave at which the automobile distributor points open, the position at which the spark-plug gap ionizes and fires, and the position at which the distributor points close. Also illustrated on the waveform are the two major components of the ignition spark, the capacitive and inductive components. To determine the contribution to interference by each component of the ignition spark, an examination of the current during each

phase of the pulse waveform is required. The current associated with the capacitive component of the wave is highly oscillatory and covers a wide frequency range from HF through UHF. Hence, the major source of interference from the ignition system is due to the capacitive component of the ignition spark. The inductive component contributes a negligible amount to the interference being radiated except possibly at the lowest frequencies emitted. Restrictions on the use of vehicles at installations are issued by the activities.

(3) Rectifiers. Rectifiers have been described as nonlinear circuit elements having the property of passing a greater current in one direction than in another.

Rectifiers can produce at least two types of interference: harmonic and broadband. Harmonic interference is generated as a result of the nonlinear characteristic of a rectifier. The signals produced include the applied frequency, its harmonics, and associated intermodulation products. These often extend over hundreds of megahertz throughout the spectrum. When an applied signal is nonsinusoidal in waveform or of high frequency, the cutoff time of the rectifier becomes very short, and it generates broadband emission.

Mercury vapor and gaseous-type rectifiers can generate interference because of the manner in which they function. The continual establishment of new conduction paths through mercury within the tube and the continual breakdown of existing paths, all with considerable arcing, create interference in addition to the usual harmonic and switching type interference produced.

(4) Electrical Equipment. Electrical equipment constitutes a serious source of broadband as well as narrowband interference. Broadband emission is generated during the commutation process by the brushes and the armature, arcing in bearings, friction between moving parts, internal arcing, and control windings. Narrowband emission arises from poor machine symmetry causing the generation of harmonic frequencies.

Brush-type motors are the most offensive generators of potential interference of all the types of rotating machinery. Machines that use sliprings, such as induction motors and alternators, produce emissions that are generally much lower in amplitude relative to those produced by the brush-type motor. The most commonly used brush-type motor is the universal motor. This motor has the convenient ability to run on either AC or DC with similar characteristics (provided both stator and rotor cores are laminated). Because of their rotation speeds (1500 to 15,000 r/min) and their versatility, these motors are used in a number of domestic as well as industrial jobs. Portable electric drills, saws, and sanders, as well as electric shavers, fans, blenders, clocks, and a host of office appliances all make use of universal motors.

Basically, the emissions generated by these sources can be considered random, since the emissions are generally high-speed impulse-type signals. The frequency output of a brush-type motor ranges from 10 kHz to 1000 MHz.

The devices should not be used in the vicinity of electronic equipment unless they comply with applicable EMI requirements, such as those specified in MIL-STD-461 .

(5) Power Lines. A source of impulse noise with a high duty cycle that is generally important only at frequencies below 100 MHz is a power line. Power lines generate 60 or 400-Hz noises in receiving systems primarily due to malfunctions, faults in insulating material, or loss of line insulation. Discontinuities in a power line, a prime source of corona emissions, can be found at the high-power insulator tie-off points along the line. It should be emphasized that power line emissions can become extremely important if discontinuities or malfunction along the line occur. Requirements for control of radiated emissions from overhead power lines on Naval installations are detailed in MIL-STD-461. In addition, care should be exercised in adhering to minimum separation from commercial power lines, such as presented in other Naval Shore Electronics Criteria Handbooks.

(6) Fluorescent and Other Lamps. Fluorescent lamps, mercury vapor lamps, sodium lamps, and neon signs are known causes of interference. Fluorescent and neon lamps produce pulse-type interference which may be conducted by and radiated from the power supply circuit. Mercury arc lamps and sodium lamps produce arc-type (impulse) radiation. In these last two types of lamps, the energy level is high due to the high currents and voltages required for operation. Usually, line filters and shielding are required for use in all such installations. The generated interference from these sources has been shown from tests to be most severe at frequencies below 10 MHz.

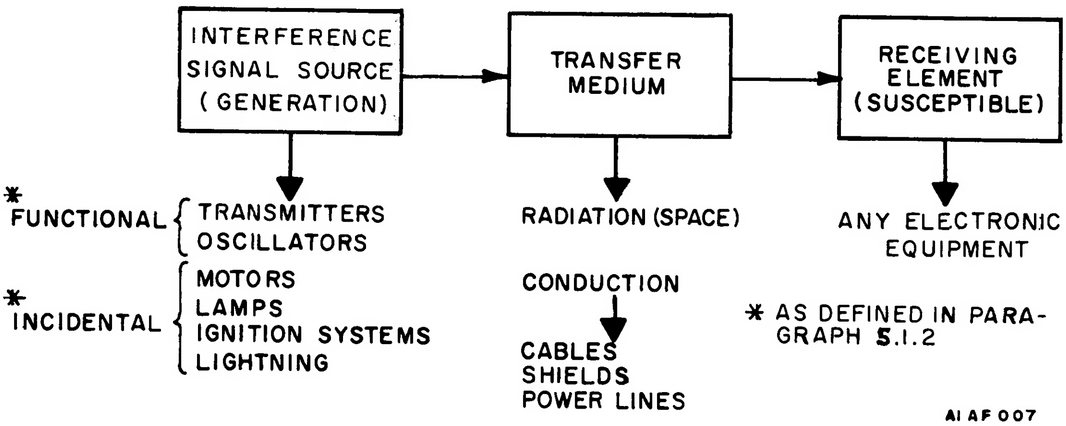

Figure 5 - 1. Three Basic Components of Interference

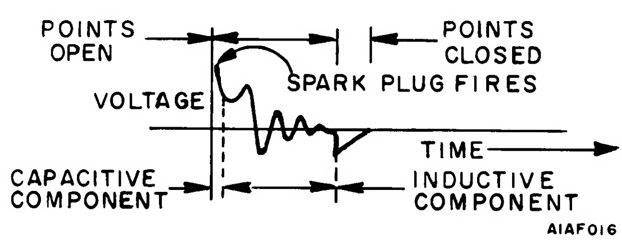

Figure 5 - 2. Typical Voltage Waveform Across Automobile Spark-Plug Gap

(7) Natural and Inherent Sources of Interference. These refer to phenomena originating in the earth's atmosphere and beyond, and to the noise inherent within electronic equipments. These do not generally cause interference in equipment other than sensitive communication and radar systems because of the limited power levels associated with natural sources. CCIR Report No. 322 provides information for determining natural emission levels and is useful in performing EMC site surveys.

(a) Atmospheric Interference. Atmospheric effects are erratic in character, consisting of short, randomly recurring pulses completely without regularity in phase or amplitude, and energies not confined to a particular band. The average power level is relatively constant during any given hour although it may vary considerably over a longer period of time. Atmospheric fluctuations depend on such things as frequency, time of day, season, location, and weather conditions.

Atmospheric emission occurs predominantly in frequency regions below 50 MHz and it dominates all other natural interference sources below 30 MHz. It is usually the limiting factor in communications within this spectrum and decreases rapidly above 30 MHz. Figure 5-3 shows typical daytime and nighttime atmospheric emission levels as measured by a ground antenna.

Reception of atmospheric emissions may be reduced by decreasing antenna beamwidth, sidelobe level, and response bandwidth, while increasing antenna directivity and transmitted power. The values presented on figure 5-3 are typical for tropical ground stations.

(b) Cosmic Interference. Cosmic emission originates beyond the earth's atmosphere and is generated, to some degree, in all areas of the universe. Like atmospheric emission it consists of short, randomly recurring pulses completely without regularity in phase or amplitude, and its energy is not confined to a particular band. The cosmic signal intensity varies with celestial longitude and frequency. On the surface of the earth, cosmic-caused interference is effectively confined to UHF and VHF frequency regions because of absorption and reflection of other frequencies. The true intensity range of this phenomena above ionosphere shielding is as yet unknown for lower frequencies. It is most prevalent below 250 MHz, while solar-caused interference extends beyond 30,000 MHz. Major sources of galactic phenomena are the Milky Way and the sun. By using narrow bandwidth antennas and the highest frequency, interference from these sources can be greatly reduced. Figure 5-3 indicates typical values of cosmic power levels measured by a skyward-directed, high-resolution antenna.

(c) Solar Interference. Solar radiation emanates from sources located in the chromosphere and corona of the sun. The sun behaves, however, very much like a black-body radiator at 6000° K for frequencies in the infrared and visible light spectrum, although it emits considerably more radiation than can be accounted for by black-body analysis at lower frequencies. The lower frequencies are generated in the corona and the higher frequencies in the chromosphere, with both contributing radiation at intermediate frequencies. Because the source location varies in surface depth, the apparent temperature for each frequency also varies accordingly. The intensity of solar radiation fluctuates with a periodicity of weeks or months and corresponds to sunspot activity. It increases during periods of sunspot activity and decreases when there is less sunspot activity. These periods of increased radiation last several days at a time. At such times, interference levels may be 10 to 20 dB greater than the normal level of a quiet sun. At lower frequencies, solar radiation does not fluctuate as much as it does at high frequencies. Radiation is first noticed at the higher frequencies; afterwards, at the lower frequencies. The radiation generally occurs in bursts that are greater in intensity than the general background interference level. The radiation accompanying these storms is strongly circular in polarization. Accompanying solar flares are outbursts that last several minutes and increase the emission level of the sun by many orders of magnitude. Sometimes the frequency spectrum of these outbursts is quite wide and involves the major portion of radio frequencies now in use. Figure 5-3 shows power levels for an active, quiet, and violent sun. These levels were determined for an antenna oriented toward the sun with a beamwidth nearly equal to the solar diameter.

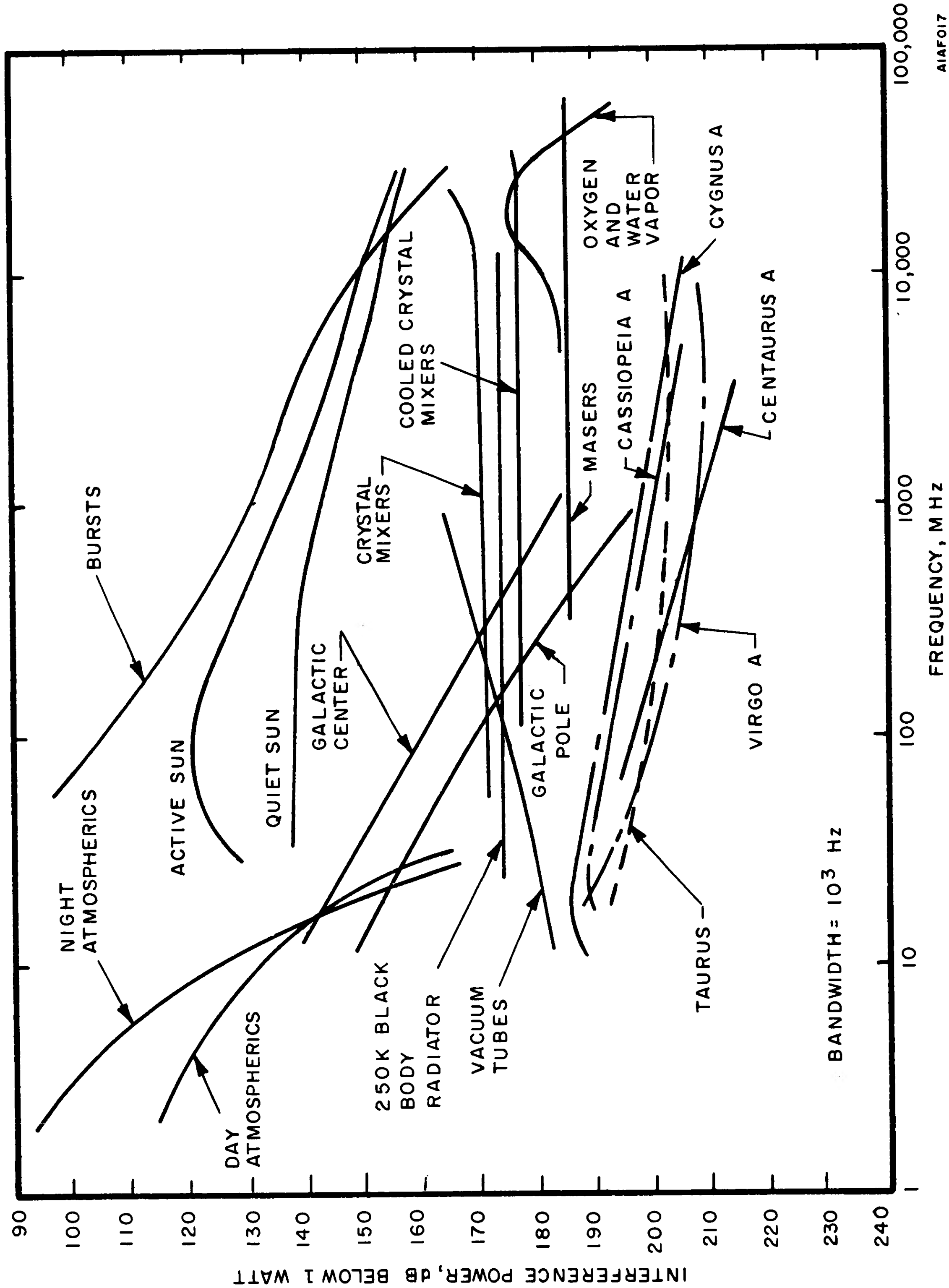

Figure 5-3. Interference Power vs. Frequency for Various Sources

(d) Galactic Point Sources of Interference. Discrete emission sources of extraterrestrial origin have been observed since 1946. When a source is sufficiently small, it is considered a point source. Most point sources are termed radio stars, but have not yet been shown to correspond to actual optically visible stars. Usually, if a source subtends an angle less than one degree, it is considered localized, and if more than one degree, an extended source.

Many radio stars have been discovered in the last decade since the advent of radio astronomy. The use of low-noise receivers increases the possibility of discovering more radio stars Only a few of these sources, however, emit electromagnetic energy of sufficient magnitude to warrant consideration as important sources of background interference to present receiving systems. The levels detected from five of the more important radio stars are shown on figure 5-3. The values used were converted from flux density to power, assuming an effective capture of one square meter.

(e) Inherent Sources of Interference. This source of interference energy was described as self-generated noise within the receiving system. Generally, this noise can be traced to thermal noise, shot noise, partition noise, flicker noise, collision ionization, and induced noise.

Thermal noise is primarily caused by agitation of electrons due to heating, while shot noise is due to the random emission of electrons from a cathode. Partition noise primarily arises in pentodes from the random fluctuations in the current division between the screen and the plate. Flicker noise is due to the spontaneous emission of particles from an oxide-coated cathode (usually more noticeable at low frequencies) and collision ionization refers to a random noise generated by the ionization of a few gas molecules which remain in a vacuum tube or are present in a gas-filled tube. Induced noise is prevalent primarily at ultra-frequencies and is a random noise generated from fluctuations in the induced current in the electrode leads of a tube.

Each of the previous noise descriptions has been applicable to tube-type noise. However, many of the noises described are also found in semiconductor systems. A transistor emits thermal noise and random noise due to the random motion of majority carriers crossing emitter and collector junctions. Also, a partition effect due to the fluctuations in the division of current between the collector and base is generated. The noise power in a transistor is inversely proportional to frequency, and is dependent on the quiescent conditions of the semiconductor material.

5.1.3 Transfer Medium

Paragraph 5.1.1 provided information on the nature and sources of interference-causing signals. To cause interference, a potentially interfering signal must be transferred from the point of generation to the location of the susceptible device and may occur over one or several paths. Basically, there are only two modes of signal transference, conduction or radiation.

a. Conducted Emission. Conducted emission refers to signals that are transferred over common interconnections between a source and a receiving device, i.e., wiring, cabling, or any metallic structure. A complete circuit path is necessary for this to occur, that is, there must be a direct connection between two circuits, and in addition, a return path. The return path can be via a lead wire, a mutual impedance, or a common ground plane or return. Undesired signals coupled by ground loops or by common connections are especially prevalent. Figure 5-4 shows a source coupling to a receiving device by conduction through common power supply wiring.

The propagation of conducted emission generally conforms to conventional circuit theory. The magnitude of a resulting current, therefore, depends on total loop impedance and the voltage sources within the loop.

(1) Circuit Coupling. Two circuits are said to be mutually coupled whenever voltages or currents in one circuit produce corresponding voltages or currents in the other circuit.

The sharing of a wire or a junction point between two or more circuits can result in common impedance coupling, wherein current in one circuit causes a voltage to appear in another circuit. The interference voltage level so produced is dependent upon the magnitude of the common impedance. Thus, circuits characterized by high impedances (and low current levels) are highly susceptible to interference.

Every portion of a circuit has capacitance between it and every other portion, so that any voltage variation within the circuit tends to produce current through these capacitances. Two conductors in close proximity, for example, will have a capacitive reactance between them, whose effective value varies with the distance between the conductors, their size, and the frequency of the interfering signal. Note that the effect of capacitive coupling increases with increasing frequency. The interposing of a shield (or using shielded wires in the case of conductors in proximity) will attenuate the current flow, but will not eliminate the capacitance.

Since the various circuits in any equipment exist as closed loops, mutual inductances are present which act as the mechanism for interaction between the loops. This interaction between loops is called inductive or magnetic-field coupling and may be thought of as a transformer action between the interference source and the sensitive circuit. Thus, where a current variation occurs in one circuit, a varying electromagnetic field is produced which induces a voltage into any other circuit loop linking the flux of the field. The amplitude of the induced voltage is directly proportional to the area of the circuit loop which encloses the flux from the first circuit. Circuits characterized by low impedances (and high current levels) are particularly susceptible to magnetic field coupling. Note that the effect of inductive coupling increases with increasing frequency. The interposing of a shield or the repositioning of the circuit elements or wiring can reduce inductive coupling to zero.

The coupling effects described, although actually classed as transmission by radiation, are analytically described using the methods of circuit analysis. In those cases, however, where the separation distances become relatively large compared to the circuit coupling elements, circuit analysis equations become invalid, and exact relationships must be obtained through the use of electromagnetic field theory.

b. Radiated Emission. Electromagnetic fields are produced by time-varying currents through circuit elements, and are radiated outward from the elements according to the laws of wave propagation. Interference occurs when the radiated field encounters other circuit elements, causing currents that produce unwanted effects to be induced in them. Since both the source, or radiating element, and the receiving element can be thought of as antennas, the transfer mechanism can be analyzed by considering the basic properties of antennas, their corresponding electromagnetic fields, and the effects of the propagation medium on the radiated signal.

It has been found that, in order to define the properties of the field produced by an infinitesimal antenna element, the space surrounding the antenna can be divided into two major regions, the near field and the far field, as illustrated in figure 5-5. The near field region is subdivided into the static field region and the induction field region.

The static field exists in the volume immediately surrounding the element, and is so called because the field energy in this region remains static, in a manner similar to the energy stored in the field of an inductive coil. The field intensity in this region varies as $\frac{1}{r^3}$ where r is the radial distance from the element.

The induction field region exists further out from the antenna and is characterized by the cyclic outward and inward flow of energy as the field expands and collapses. The field intensity in this region varies as $\frac{1}{r^2}$.

The static and induction fields make up the near field region. The energy within this region is mainly reactive where no net outward flow of energy takes place. The relative shape of the antenna field pattern may vary appreciably from point-to-point.

At distances relatively far from the antenna element, the propagated energy can be regarded as existing as uniform plane waves having only transverse field intensity components. In the far field, as this region is called, the energy flow is real, i.e., no appreciable energy storage occurs, the field intensity varies as $1/r$, and the relative shape of the field pattern is independent of the distance from the antenna element.

To summarize, the radiation (or far) field region of space is that region in which the field strength is primarily a function of the inverse distance (1/r) from the antenna. When the field strength magnitude becomes dependent on the inverse square of the separation distance, the near field begins and the induction field is defined. Moving closer to the antenna, the major field dependence is on higher-order terms of the inverse separation distance, i.e., terms of higher order than $1/r^2$. From the preceding discussion it can be seen that no exact boundary can be set for the transition distance between field regions. Each transition is a gradual one which depends on the variations of the field strength with distance.

Since transmission of an electrical signal involves propagation through a medium, the effects on the signal by the medium must be considered. During transmission, a loss is incurred due to scattering, absorption, reflection, and many other factors which, if great enough, can render the undesirable signal harmless, or if not great enough, can allow the undesired signal to reach the receiving device. Basically, it can be stated that, when a signal is radiated through the electromagnetic environment, the losses incurred in transmission are dependent on frequency, separation distance, (i.e., the distance from emitter of the electrical disturbance to the affected device), terrain over which propagation occurs, the electromagnetic properties of the medium, and many other variable factors. Many of the variable factors can change with time and thus introduce changes in the mode of propagation.

One of the most fundamental concepts of propagation loss is the free-space propagation loss. This loss is a lower limit on what should be expected when a signal is transmitted through space. This lower limit is very useful in the prediction of interference since it allows for the determination of a worse possible case of interference at a receiving device. More details on the usage of the free-space propagation loss factor will be given in the discussion of prediction methods. For the present, it will suffice to illustrate what is meant by free-space transmission loss by presenting the basic loss equation for far-field separations:

$$L = 20 (\log f + \log d) + 37 \tag{5-1}$$

where:

L = free-space transmission loss (for line-of-sight transmission) (dB).

f = frequency of signal (MHz).

d = distance in statute miles between the potentially interfering transmitter and its victim receiver.

Equation (5-1) assumes isotropic antennas, hence the gains of both the transmitting and receiving systems are assumed to be unity with respect to an isotrope.

When refinements as to the actual propagation losses are required, several conditions and types of transmission must be considered. All of the losses incurred from the many propagation factors simply reduce the strength of the potentially interfering signal even further than that provided by the free-space losses.

5.1.4 Equipment Susceptibility

a. General. Any equipment or device capable of responding to electromagnetic fields or to electrical signals must be considered a suspect for susceptibility to emissions. Whereas the previous sections described the generation and transmission of signals, this section deals with the receipt of, and reaction to, these signals by various equipments.

In the study of equipment sensitivity, two broad categories can be established: equipments that are frequency selective, and those that respond over a wide frequency band. The former category includes primarily, communication, radar, and other type radio receivers. Examples of devices that respond over a wide range of frequencies are meters, indicator lights, control circuitry, wideband amplifiers, and relays.

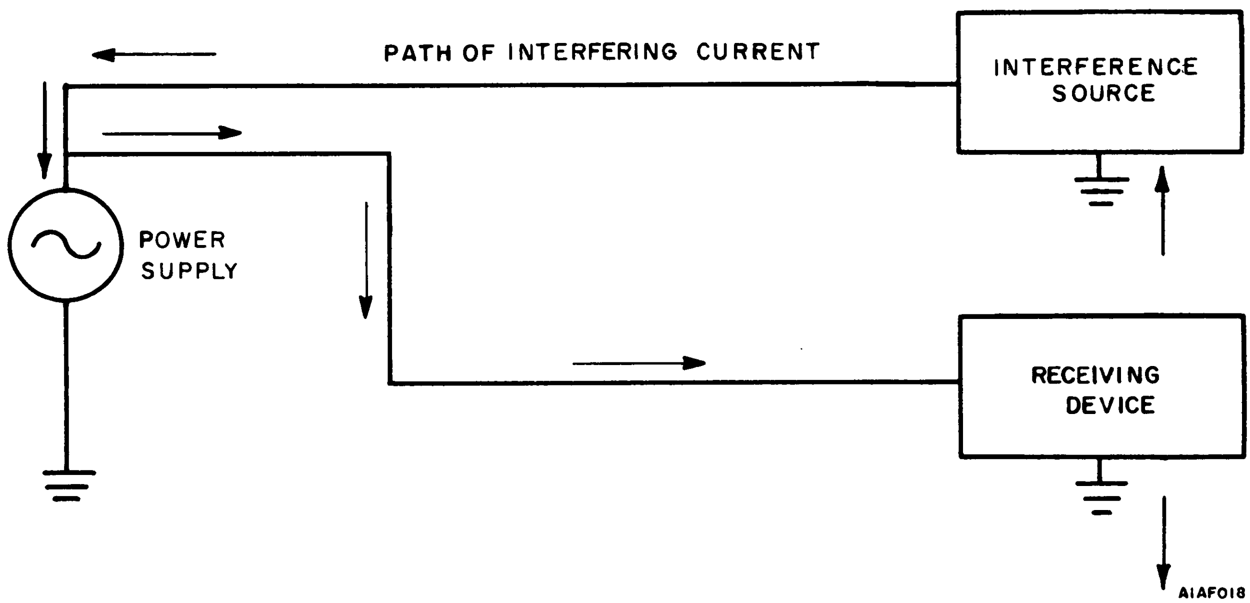

Figure 5 - 4. Interference Coupling by Conduction

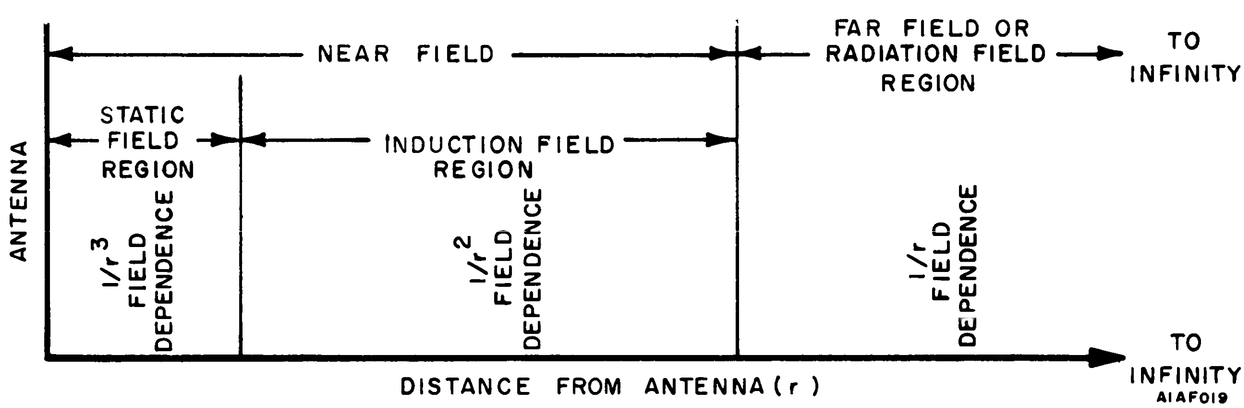

Figure 5 - 5. Electric Field Regions of a Radiating Element

It should be noted that susceptibility is not an absolute, definitive property of a piece of equipment or device, but must be related to the particular type of emission and its mode of entry into the equipment. The establishment of susceptibility criteria or limits for various equipments is purely subjective, and is based on the decision as to what constitutes an unacceptable degradation of output or performance. In voice communications, for example, a signal-to-noise ratio of zero to 6 dB may be regarded as just acceptable, ratios up to 20 dB as satisfactory, and above 20 dB as excellent.

The specification of susceptibility of an individual equipment may vary when a distinction is made between its function as an isolated equipment and its use as part of a system or installation. In the latter case, performance specifications and the degree to which the system or installation depends on its individual equipments will influence the equipment susceptibility level. System or installation performance will then be dependent upon its most susceptible equipment.

b. Entry Mechanisms. In the previous section it was stated that undesired signals are transmitted by conduction or radiation, or both. Such signals may gain entry into equipment via the various cables, connectors, through the grounding system, by sensors connected to the equipment or by direct irradiation of the equipment by an electromagnetic field.

Basically, there are two modes of entry of an undesired signal: the normal, or differential mode, in which the unwanted signal is introduced into the desired signal; channel through the same path as that of the desired signal, and the common-mode, in which the unwanted signal is introduced into the desired signal channel from a source having at least one terminal which is part of the desired signal channel. That is, the undesired current path is only partly common with the signal current path, usually through the chassis or ground system. Figure 5-6 depicts examples of the entry mechanisms. In figure 5-6A unwanted current is conducted from the source, located in equipment A, to the receiving unit, equipment B, via common input leads. If the common source is supplying the desired signal to the two equipments, then this situation can be classified as differential mode; if the common source is a power supply, then entry of the undesired current would not be over the normal signal path, and the coupling would be classified as common-mode. A second differential-mode case is shown in figure 5-6B in which entry occurs via either magnetic or capacitive coupling between signal leads and an adjacent power or transmission line. In this case, transmission of the undesired signal is by radiation. Common-mode coupling in which the common path is the ground return, is shown in figure 5-6C. Two sources supplying their individual loads via common ground returns are also shown in figure 5-6C. The circuit has been redrawn to include the impedance of the ground path. As a result of the finite ground impedance shared by the two signal paths, coupling between the paths takes place. This type of coupling is quite common in equipment design and may be minimized by using various techniques to avoid such common paths, e.g., use of separate grounds, heavy ground fuses, etc. Design details to avoid common-mode coupling are given in Chapter 6. Direct radiation entry is illustrated in figure 5-6D. Antennas are, of course, a major point of intrusion in radio receivers. Radiation which gains entry into receivers via their associated antennas is discussed below and from an inter-system viewpoint in the section covering prediction and analytical techniques. Radiation may gain direct entry into equipments through ventilation holes, meter and other panel openings, through inadequate shields, or may cause currents to be induced on equipment cabling, connectors and other wiring. The latter cases usually originate within a system or equipment and may be regarded as intrasystem coupling.

c. Equipment Susceptibility Characteristics.

(1) Wideband Equipment. The term, wideband equipment, refers to all electrical and electronic devices other than those which are tunable to or fixed at a selected band of frequencies. In general, because of the complexity of types, arrangements, and operational characteristics of equipment, and because of the many types of interference causing signals, entry modes and interactions. the susceptibility characteristics of this equipment category have not been completely documented, or standardized. Susceptibility of individual equipments used for specific requirements is best determined by test, either by simulation of interference signals or under actual operating conditions. Requirements and test methods are outlined in MIL-STD-461 and -462, respectively. A brief qualitative discussion of some susceptibility characteristics follows.

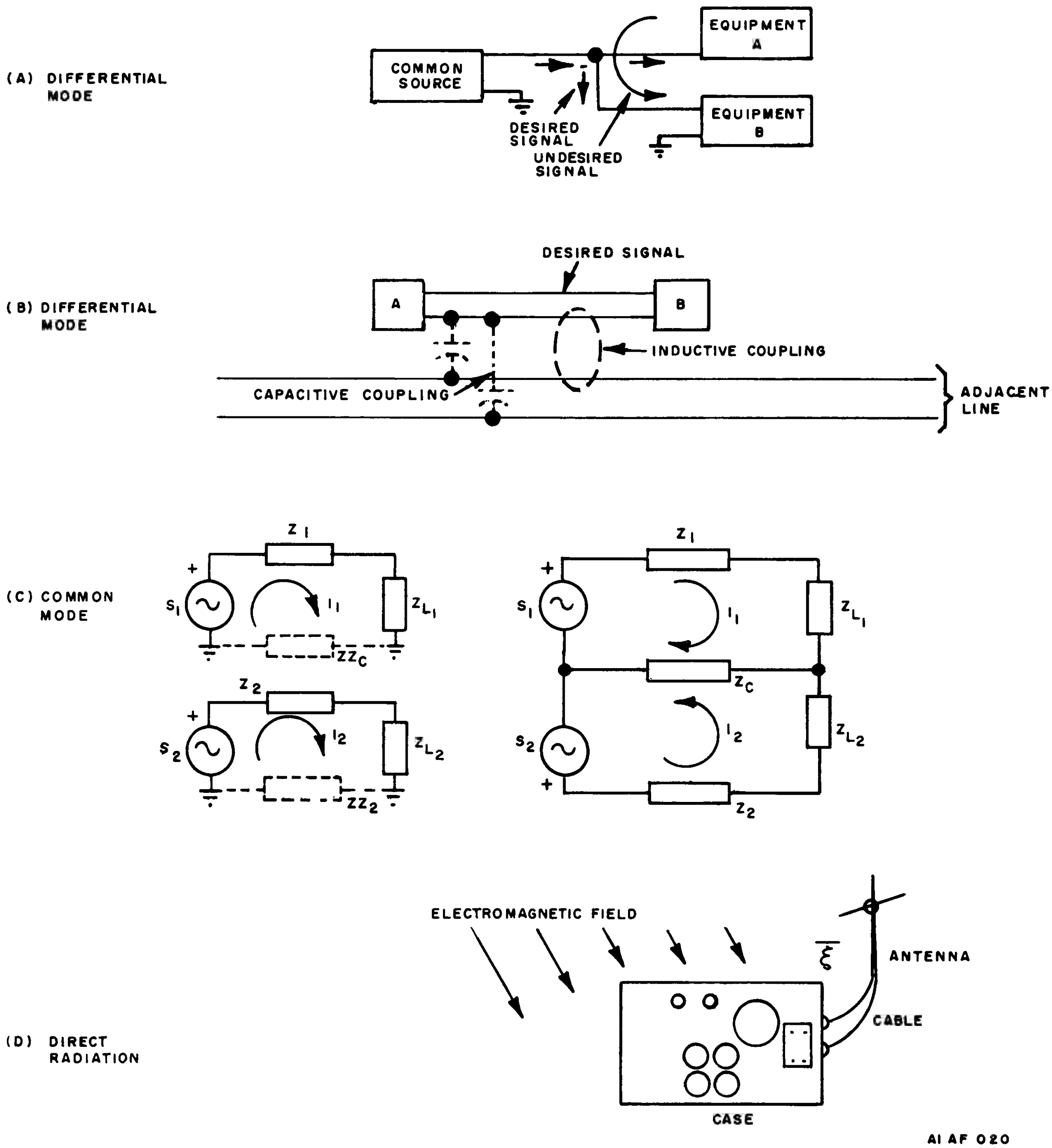

Figure 5 - 6. Signal Entry Paths

(a) Digital Computers. Since operation of digital computers depends upon pulses and levels of fixed amplitudes occurring at correct predetermined times they are particularly susceptible to pulse-modulated high frequency radar signals. Experimental investigations have demonstrated false switching in flip-flops and logic gates, deteriorated legitimate signals and erroneous outputs in which the rise-time, as well as the amplitude, of the interfering pulse were important. Ordinarily, basic solid state circuitry is ostensibly more susceptible to interference emissions than its vacuum tube counterpart. This may be traced to the lower operating signal levels of the solid-state computer with associated lower signal-to-interference ratios.

(b) Control and Indicating Devices. This equipment category frequently includes low-level, high-impedance input-type amplifiers that are used in the processing of sensor signals, control of electromechanical devices, display of transducer sampling, and many other functions. Examples are servo amplifiers, DC amplifiers, indicators and sensitive test equipment Since this type of equipment frequently operates by modulation of the 60 Hz and 400 Hz power frequencies they are particularly susceptible to power line transients and stray coupling to wiring, transformers, etc., operating at power frequencies. Because they operate at relatively low signal levels, amplifiers of this type are troubled by common-mode coupling at their input terminals. Rectification of high-frequency signals by non-linear circuit elements can cause saturation or de-sensitization of gain characteristics, or cause parasitic oscillations.

(c) Displays. Cathode-ray tube type displays are susceptible to emission from radars, communication transmissions, ignition systems, and other equipments. The main effect is the disruption of the visual information presented to the equipment operator. Cathode-ray tubes are susceptible to stray magnetic fields which act to deflect the electron beam. The circuits which process the video, or information signal, and those that generate the required sweeps, are subject to power line and common-mode coupling as outlined in the previous section. Interference in sweep circuits is characterized by distortion of the display (by causing the sweep to be non-linear), while undesired responses in the video sections may appear as intensity modulations.

Nixie tube, solid-state and other alpha-numerical type displays generally use digital logic gating to form the read-out and are, hence, subject to the same responses as digital computers, i.e. false switching and loss of synchronism leading to erroneous readouts.

(2) Frequency Selective Equipment. Frequency selective or narrowband equipment includes all equipment types which are tunable over, or fixed to operate at, a selected range of frequencies. Receivers of all types, having the reception of electromagnetic energy as their prime function, form the major class of devices in this category. Since they are deliberately designed, in many cases, to optimize their sensitivity, and because of their frequency band restrictions, receiving devices are subject to more numerous, more complex interference situations than other equipment types. Examples of radar interference are shown in figure 5-7. Tables 5-1 and 5-2 list interference modulation characteristics on radar and communication receivers, respectively.

Receivers may be classified into two major design types: the heterodyne and the crystal video type receiver, the designs of which are documented in the literature.

5.2 BASIC RADHAZ CONSIDERATIONS

5.2.1 General

Whereas the previous discussion concerned itself with the interaction of electromagnetic energy with communications-electronics equipments from the standpoint of performance degradation, this section deals with the basic effects of electromagnetic radiated energy on personnel, flammable mixtures, ordnance, and electronic hardware from a hazard standpoint.

Refer to NAVELEXINST 5100.4 for information on hazards and NAVFACINST 8020.3 regarding site approvals for transmitter and antenna installations.

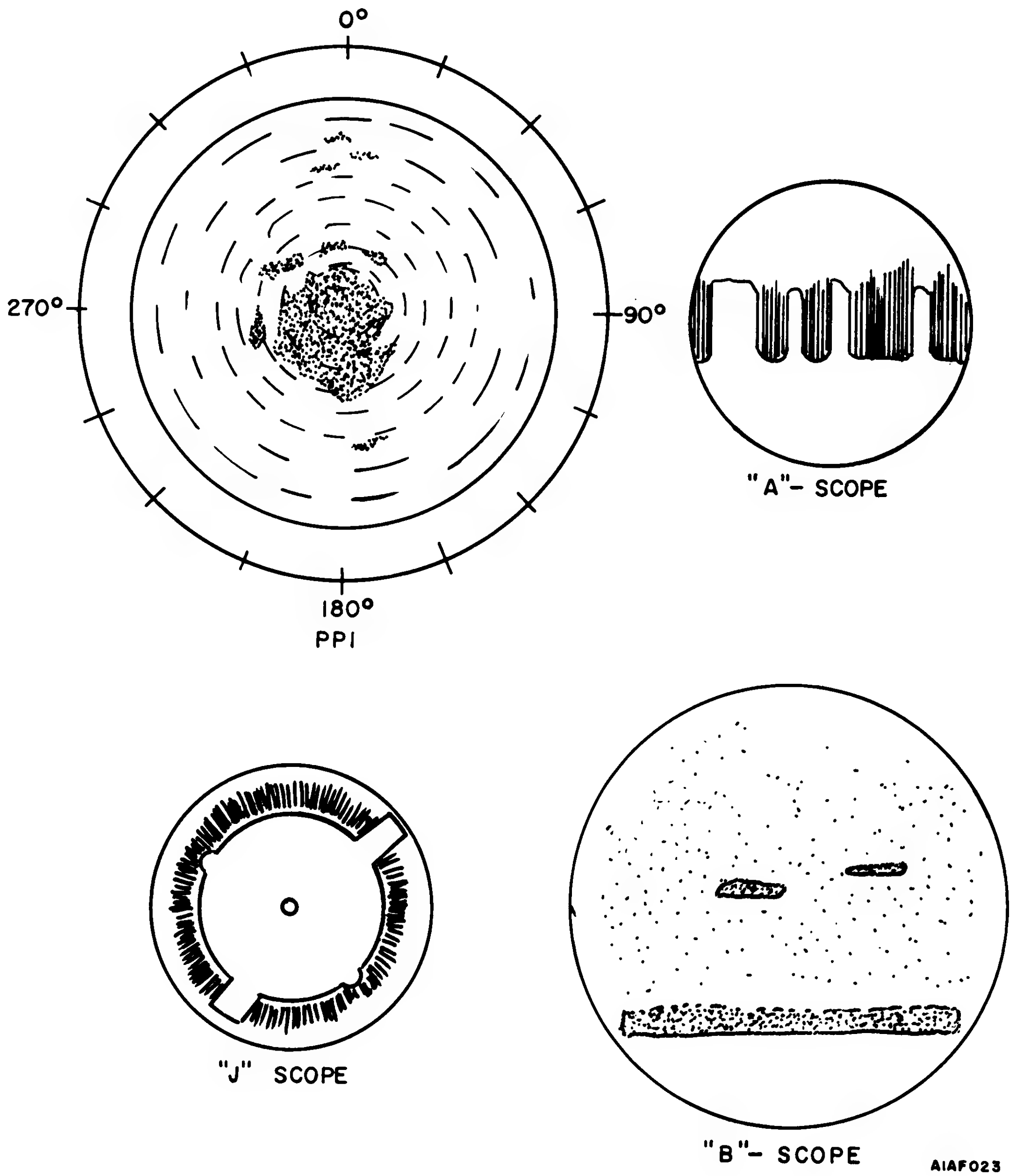

Figure 5 - 7. Interference Patterns on Radar Scopes

Table 5-1. Interference Modulation Characteristics On Radar Scopes

SCOPE TYPE	BROADBAND		NARROWBAND	
	PERIODIC	RANDOM	UNMODULATED	MODULATED
PPI	Fixed or moving dot or spiral pattern.	Random dot pattern or general increase in noise level (pattern cannot be fixed by adjustment of Pulse Repetition Frequency (PRF) or antenna scan rate)	Variation in the intensity of display.	Very rapidly changing dark and light scope patterns.
A	One or more fixed or moving pulses (running rabbits). Interfering PRF can be adjusted for one fixed (or slowly moving) pulse when the scope is adjusted for maximum range.	Random positioned pulses, or general increase in noise level (grass). Sometimes a reduction in MVS.	Change in noise level generally a reduction. The MVS detection capability will be reduced.	Rapid variations in the noise level with extraneous noise on scope.

Table 5-2. Interference Modulation Characteristics at Communications Receiver Audio Output

RECEIVER AUDIBLE OUTPUT	CHARACTER OF INTERFERENCE	POSSIBLE SOURCE OR MECHANISM
Reduced noise level (or steady tone with BFO operating)	Carrier (only)	Cochannel, spurious intermodulation
Pulsed variation in noise level (or pulsed tone with BFO operating)	Unwanted CW or digital transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Pulsed variation in noise level (two pulsed tones with BFO operating)	Unwanted RADTT (FSK) transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Pulsed tone	Unwanted MCW transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Added normal or distorted voice	Unwanted voice transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Whistling or squealing	Unwanted transmission or intermediate frequency oscillation	Adjacent channel, cochannel, spurious, intermodulation, cross modulation, parasitic and IF oscillation
Rapid variation in noise level (or several pulsed tones with BFO operating)	Unwanted facsimile transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Steady tone or whining	High rate periodic pulses	Radar, rotating machines
Buzzing	Medium rate periodic pulses	Buzzers, vibrators
Popping	Low rate periodic pulses	Ignition systems, magnetos
Frying	High rate random pulses	Electric arcs, continuously arcing contacts
Sputtering	High rate random pulses	Arc welders, arc lamps, diathermy
Clicking	Low rate random pulses	Code machines, electric calculating machines, mercury arc rectifiers, relays, switches, teletypewriters, thermostatic controls, electric typewriters
Crackling		Static or corona discharges
Sharp crackle		Ambient noise

5.2.2 Hazards to Personnel

The human body is composed of various tissues which may be considered as a transmission medium exhibiting the characteristics of a complex dielectric material.

At certain frequencies, the thickness of the skin and fat tissue layers may act as a quarter-wave matching transformer to match the impedance of air to the input impedance of the deep tissues, resulting in a transfer of power into the deep tissues, with very little loss and little heating of the skin and fat tissue layers near the body surface.

The penetration of energy into the body and its absorption (loss of energy), and reflection will depend not only upon the physical dimensions and dielectric constant of the tissues, but also upon the frequency (wavelength) of the electromagnetic radiation.

When electromagnetic energy is absorbed into tissues of the body, heat is produced in the tissues. If the organism cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and, if the rise is sufficiently high, in death of the organism. The body's ability to dissipate heat successfully depends upon many related factors, such as environmental air circulation rate, humidity, air temperature, body metabolic rate, clothing, power density of the radiation field, amount of energy absorbed, and duration of exposure (time).

When the body is irradiated by energy in the form of a beam originating from a point source, the total body surface is usually not exposed. Only the portion facing the source is exposed, provided that no reflections of energy occur from nearby reflecting surfaces to cause complete irradiation of the body. The temperature elevation produced by the exposure obviously depends on the ratio of the body surface irradiated to the total body surface. The larger the area exposed, the higher the temperature rise, and the greater the hazard. The increase in body temperature to the tolerance threshold (the point at which biological effects begin to occur) may possibly be delayed if the exposure occurs in an environment of low ambient temperature and adequate air circulation. It is interesting to note that sedatives and tranquilizers interfere with the body's ability to regulate temperature and lose heat.

Certain organs of the body are considered to be more susceptible than others to the effects of electromagnetic radiation. Organs such as the lungs, the eyes, the testicles, the gall bladder, the urinary bladder, and portions of the gastrointestinal tract are not cooled by an abundant flow of blood through the vascular system. Therefore, these organs are more likely to be damaged by heat resulting from excessive exposure to radiation. Of the organs just mentioned, presently available information and experience indicate that the eyes and testicles are the most vulnerable to microwave radiation.

a. Relationship of Physical Size to Wavelength. When considering the biological effects produced by electromagnetic radiation, the wavelength (frequency) of the energy and its relationship to the physical dimensions of object exposed to radiation become important factors. It has been determined that for any significant effect to occur, the physical size of the object must be the equivalent of at least a tenth of a wavelength at the frequency of radiation.

A comparison of frequency, propagation wavelength, and the number of physical wavelengths represented by a man 1.7 meters (5 ft. 7 in.) tall is given in table 5-3.

From the values given in the table, it can be seen that the man chosen for the example is 1.7 wavelengths tall at 300 MHz, 17 wavelengths tall at 3000 MHz, and 56.6 wavelengths tall at 10,000 MHz. As the frequency of radiation increases, the wavelength decreases, and the man's height represents an increasingly greater number of electrical wavelengths. As the frequency is decreased, the wavelength increases, and the man becomes a less significant object in the radiation field. Thus, at 30 MHz the man's height (1.7 meters) represents 0.17 wavelength, and at frequencies below 17.7 MHz it represents less than 0.1 wavelength.

Table 5-3. Comparison Of Frequency, Wavelength, And Equivalent Number Of Wavelengths Of Man 1.7 Meters Tall

FREQUENCY (MHz)	WAVELENGTH		EQUIVALENT NUMBER OF WAVELENGTHS
	METERS	cm	
3	100	100,000	0.017
30	10	10,000	0.17
300	1	100	1.7
3000	0.1	10	17.0
10.000	0.03	3	56.6

From this discussion it can be seen that the man chosen for the example, whose physical height is 1.7 meters and represents a tenth of a wavelength at 17.7 MHz, is an increasingly larger object for all frequencies above 17.7 MHz. Neglecting other physical measurements of the body, it is seen that if the man is considered to be a vertical receiving antenna, his electrical length (height) depends upon the frequency of radiation. Also, as the radiation frequency is increased and the wavelength becomes progressively shorter, the dimensions of parts and appendages of the body in themselves become increasingly significant in terms of the number of equivalent electrical wavelengths.

Practically speaking, the human body is a three-dimensional mass having width and depth, as well as height. Therefore, when a man stands erect in an electromagnetic field, he represents an object which not only has a height dimension, but also has width and depth dimensions that can be expressed in terms of wavelength. Again comparing the physical characteristics of the human body to those of a broadband receiving antenna, when the body is oriented so that any of these major body dimensions is parallel to the plane of polarization of the electromagnetic energy, the effects produced are likely to be more pronounced than when the body is oriented to other positions.

b. Summary of Thermal Biological Effects. The knowledge gained from laboratory experience concerning the effects of radiation within the range of frequencies from 150 to 10,000 MHz (200 to 3 cm wavelength) are outlined in table 5-4 and can be summarized as follows:

(1) The percentage of absorbed biologically effective energy approaches 40 percent of the incident energy for frequencies below 1000 MHz (30 cm) and for frequencies above 3000 MHz (10 cm).

(2) The percentage of absorbed biologically effective energy is between 20 and 100 percent of the incident energy for frequencies between approximately 1000 and 3000 MHz (30 to 10 cm wavelength).

(3) The sensory elements of the body are located primarily in the skin tissues. For this reason particular caution must be exercised in the presence of radiation frequencies below 1000 MHz because the resultant heating will not be detected as readily by the human sensory system. Radiation at frequencies below 1000 MHz causes heat to be developed primarily in the deep tissues as a result of the penetration of the energy. The energy absorbed in body tissues may be as high as 40 percent of the incident arriving at the body surface.

Table 5-4. Resumé of Biological Effects of Microwaves

FREQUENCY (MHz)	WAVELENGTH (cm)	SITE OF MAJOR TISSUE EFFECTS	MAJOR BIOLOGICAL EFFECTS
Less than 150	Above 200	Under investigation	
150 - 3,300	200 - 10	Internal body organs	Damage to internal organ from overheating
		Lens of the eye	Lens of the eye particularly susceptible and tissue
3,300 - 10,000	10 - 3	Top layers of the skin,lens of eye	Skin heating with the sensation of warmth
Above 10,000	Less than 3	Skin	Skin surface acts as reflector or absorber with heating effect

(4) Frequencies greater than approximately 3000 MHz cause heating of tissues in much the same manner as does infrared radiation or direct sunlight; therefore, the sensory reaction of the skin should normally provide adequate warning of the presence of electromagnetic radiation. In general. the depth of energy penetration decreases rapidly with an increase in radiation frequency, and absorption occurs almost completely in the surface of the body where skin tissues and the sensory elements are located. Also, reflection of energy at the surface of the skin occurs at the higher frequencies. Thus, the percentage of energy absorbed may approach 40 percent of the energy incident on the body surface, with a greater portion of energy being reflected.

(5) Radiation at frequencies between 1000 and 3000 MHz is subject to varying degrees of penetration and is absorbed in both surface tissues and the deeper tissues, depending upon the characteristics of the tissues themselves (thickness, dielectric constant, and conductivity) and the frequency of radiation. The percentage of incident energy absorbed varies from approximately 20 to 100 percent because of tissue factors governing impedance values, which range from complete mismatch to a near perfect match to the incident energy. Hence, this frequency range is considered the most hazardous.

c. EMR Burns and Other Hazards. Electronic equipment radiating RF energy may cause a voltage to be induced in metallic objects which approach resonance or are resonant to the transmitted fundamental frequency or one of its harmonic frequencies. The proximity and position of the radiating antenna and the directivity and polarization of the beam relative to the conductive object will govern the amount of induced voltage present. Such induced voltages may cause shock or RF burns to personnel or may produce open sparks when contact between conductive objects is made or broken. For example, tests indicate that high RF voltages are induced in metal tools, common lead pencils, etc., near the center of the radar beam where the radiated power density is the highest, and that the resulting discharge may cause an arc of sufficient intensity to ignite gasoline vapors. It is also possible that light metallic objects in the beam may become heated sufficiently to ignite flammable vapors.

Aboard ships, voltages may be induced in standing rigging, cables, parts of the superstructure, and deck loads. Measurements aboard various ships have shown that voltages of sufficient amplitudes to cause severe burns to personnel can be induced into cargo handling equipments by radiation from HF transmitting antennas.

In addition, the involuntary reaction of personnel to nonlethal EMR shock is extremely dangerous when a person is working in close quarters or in elevated locations since such reflex action can result in falls or bodily injury due to striking an object.

d. Athermal Effects. Much of the early work in the field of biological hazards concluded that the only significant biological effect of EMR was thermal in nature. In recent years however, the possibility of non-thermal effects have been discussed, some of which have been shown to be dependent on peak powers whose average value is not great enough to produce heating. Frequency dependence with no heating, has also characterized many of the observed effects. While the full significance of these effects to humans is still under investigation, an awareness of their existence should be considered.

e. X-Radiation Effects. Ionization is involved in the production of biological effects of X-radiation. All X-rays except those of very low photon energy will penetrate human tissue and form positive and negative ions. Depending upon the dosage, these ions may cause tissue damage of either a temporary or permanent nature. Unless the dosage is extremely high, there will be no noticeable effects for days or weeks or, in some cases. years after the exposure. This delay in the effect is no doubt the most important reason for cases of overdoses of X-rays, since the damage has been done long before the symptoms begin. The effects presented herein are those restricted to the incidental X-radiation from electronic equipments. See NAVMAT P-5100 and NAVMED P-5055 for other X-radiation effects.

f. Other Effects.

(1) Laser Radiation. Research encompassing that portion of the electromagnetic spectrum which includes the infrared and wavelengths in the visible region has resulted in the use of these wavelengths in devices which have military application. The laser, for example, is coming into more widespread use in such devices as rangefinders, survey transits, tracking instruments and communications equipment thus increasing the probability of personnel exposure to laser radiation.

Some of the known biological effects of exposure to these wavelengths are described below:

o Infrared. Infrared energy, using conventional sources, has been used in the military for many years in such areas as tactical communications, beacons, surveillance, missile guidance, tracking, and many other applications. Only active infrared systems, in which a source is used to generate energy which is then radiated in some manner, are potentially hazardous. These systems generally use filters to remove any visible radiation. A characteristic of the infrared portion of the electromagnetic spectrum permits the waves to be readily absorbed and the energy converted into heat. Infrared radiation does not exist as heat waves. It behaves as do radio or light waves and is transmitted in the same manner through air or vacuum. Infrared radiation can be refracted and reflected according to the laws of optics, since infrared and visible light are of the same nature. The fact that infrared radiation is readily converted into thermal energy when it strikes an object distinguishes it from other types of electromagnetic radiation. The human eye is susceptible to damage by infrared energy, since the energy may cause the development of cataracts or opacities similar to the damage caused by radio-frequency and ionizing radiations described previously. Infrared is invisible and it is therefore possible that personnel may interrupt an infrared beam (from an active system) without being aware of the fact.

o Visible Wavelengths and Ultraviolet. See figure 5-8. Potential radiation hazards from both the visible wavelengths and the ultraviolet stem mainly from their use in equipments using laser energy sources, although ultraviolet emissions have been reported from cathode-ray tube and PPI equipment. Infrared wavelengths are also generated in CO_2 type lasers, as well as by the conventional sources mentioned above. The effects of laser radiations are essentially the same as light generated by more conventional ultraviolet, infrared and visible light sources. The unique biological implications attributed to laser radiation are generally those resulting from the very high intensities and monochromaticity of laser light. Such sources differ from conventional light emitters primarily in their ability to attain highly coherent light (in phase). The increased directional intensity of the light generated by a laser results in concentrated light beam intensities at considerable distances. Laser radiation should not be confused with ionizing radiation (such as X and gamma rays) although very high power or energy densities have been known to produce ionization in air and other materials. The biological effects of the laser beam are essentially those of visible, ultraviolet, or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. This is one of the important properties that makes lasers potentially hazardous.

A laser beam striking tissue will be reflected, transmitted, and absorbed. The degree to which each of these reactions occurs depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light; darker materials such as melanin or other pigmented tissue absorb more energy.

Skin effects may vary from mild reddening to blistering and charring, depending upon the amount of energy transferred.

The effect upon the retina may be a temporary reaction or it may be more severe with permanent changes. The mildest observable reaction may be simple reddening: as the energy is increased, lesions may occur which progress in severity with hemorrhaging and additional tissue reaction around the lesion. Very high energies will cause gases to form, which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected.

Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Some residual energy may reach the retina. Ultraviolet light can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva, and usually does not reach the retina. Light in the far infrared, such as the 10 micron wavelength from the carbon dioxide lasers, is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects.

o Most higher energy X-rays and gamma rays pass completely through the eye.

o For short ultraviolet, absorption occurs principally at the cornea.

o Long ultraviolet and visible light is refracted at the cornea and lens and absorbed at the retina.

o Near infrared energy is absorbed in the ocular media and at the retina; near infrared rays are refracted.

o Far infrared absorption is localized at the cornea.

o Microwave radiation is transmitted through the eye, although a large percentage may be absorbed.

Ultraviolet light can also cause severe burns, chromosome breaks, affect cell division, metabolism, and other body processes.

5.2.3 Hazards to Fuels

Potential hazards to fuel vapors are presented by sparks (or arcs) caused by EMR induced voltages. The ability of an arc to ignite a vapor-air mixture depends upon: properties of fuels which determine their susceptibility to or ease of ignition are the flash point, flammability limits, vapor pressure, and presence of a flammable fuel-air mixture; energy contained in and the duration of the arc; and the distance or gap across which the arc occurs.

a. Fuel Types. For the purpose of this manual, the following terminologies are used:

(1) Aviation gasoline shall mean all gasoline grades of fuel for reciprocating engine-powered aircraft of whatever octane rating having the general characteristics as described herein.

(2) JET A and JET A-1 shall mean kerosene grades of fuel for turbine engine-powered aircraft by whatever trade name or designation having the general characteristics as described. JET A has a -40^{0} F freezing point (maximum), JET A-1 incorporates special low temperature characteristics for certain operations having a -58^{0} F freezing point (maximum). JP-5 and JP-6 are grades of JET A fuel as used by the U. S. military.

(3) JET B shall mean all blends of gasoline and kerosene grades of fuel for turbine engine-powered aircraft by whatever trade name or designation having the general characteristics as described herein. JET B is a relatively wide boiling range volatile distillate having a -60^{0} F freezing point (maximum). JP-4 is one grade of JET B fuel as used by the U. S. military.

b. Energy and Duration of the Arc. The amount of energy and time duration required in a spark to ignite a flammable gasoline-air mixture is still under investigation. Early experiments at the Naval Research Laboratory were primarily based on the use of DC type sparks. Also, considerable difficulty has been experienced in the laboratory in obtaining gasoline vapor-air mixtures which can be precisely controlled and readily duplicated. Therefore, propane has been used in lieu of gasoline because its ignition characteristics are similar to those of gasoline and it is easier to meter in the proper proportions with air to provide the control necessary for laboratory experimentation. It has been determined experimentally that 2.5×10^{-4} watt-seconds of energy is required in a spark of 0.01 to 1.0 microsecond duration across a plain electrode gap to ignite a propane-air mixture. The minimum quenching distance (see the following paragraph) for the electrodes used with propane was found to be 1.75 mm (0.0689 in.). The amount of DC voltage required to break down an air-gap of this dimension is approximately 2500 volts; the amount of RF voltage required to break down a similar gap is unknown but it is believed, until proven otherwise, to be approximately the same as the DC voltage value. Additional quantitative criteria are presented in paragraph 5.3.

c. Arc Gap Distance. The minimum gap distance across which the spark must discharge will have an effect upon the possible ignition of a flammable mixture. If the gap distance is smaller than a minimum value, the spark (flame) occurring at the gap will be quenched through the removal of heat (energy) by the gap electrodes themselves, therefore, a flammable mixture will not be ignited. However, if the voltage gradient is large and the gap distance is above the minimum quenching distance, the spark (flame) will have sufficient energy (heat) to ignite a flammable mixture. The minimum quenching distance is dependent upon the size of the electrodes, the nature of the dielectric (in this case the density of the vapor-air mixture), the ambient temperature and pressure, and, to some extent, the characteristics of the electrode material(s). The voltage required to break down the gap

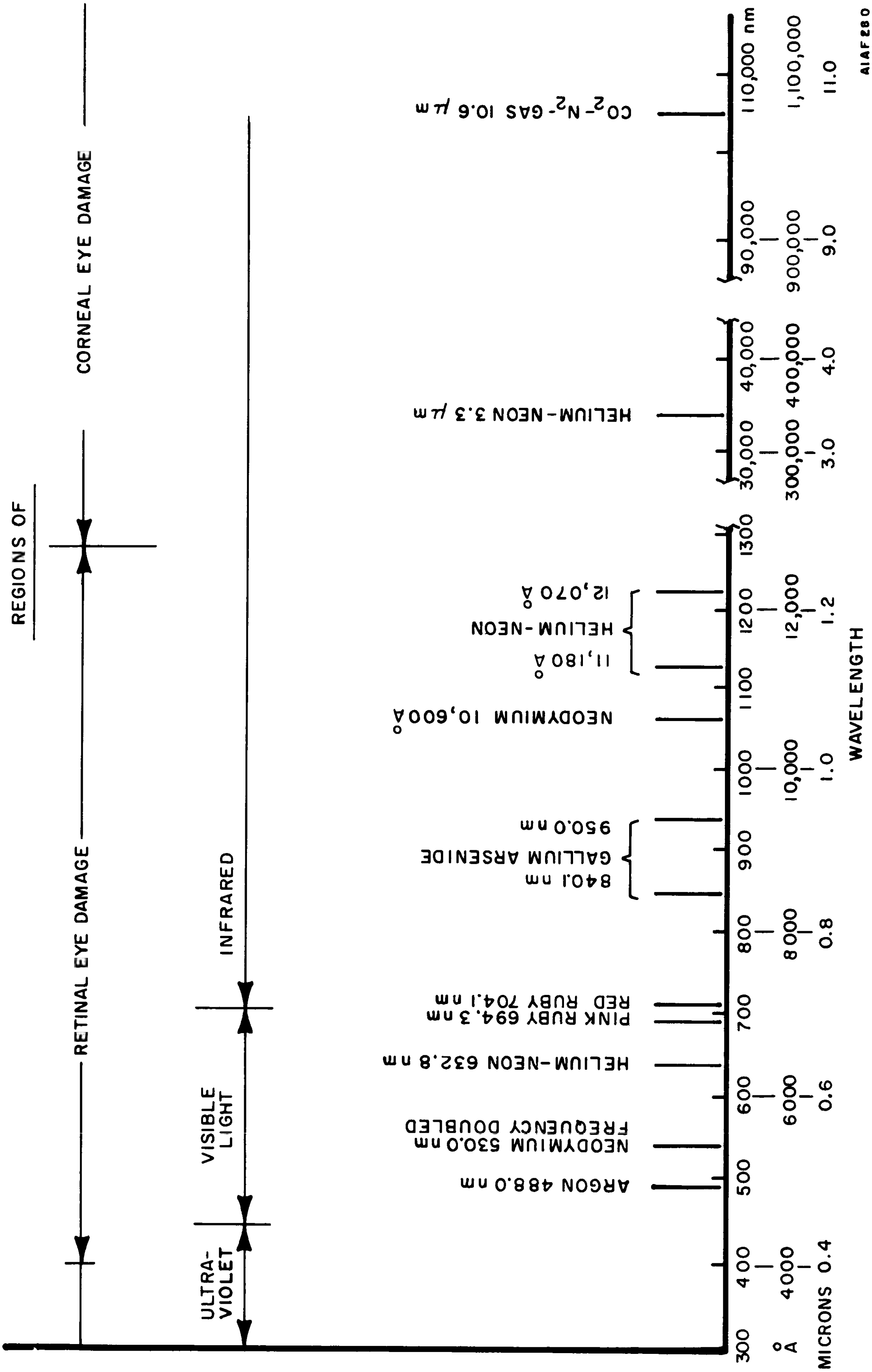

Figure 5 - 8. Laser Wavelength Chart

depends upon the density of the dielectric and the electrode spacing, assuming that there is no ionization between the electrodes which could cause a breakdown at a lower voltage. The dielectric strength of the atmosphere between the gap electrodes increases with increasing density; therefore, the greater the density of the vapor-air mixture, the greater the voltage gradient required to break down a fixed gap. Also, once the breakdown occurs, the gap distance may be increased without extinguishing the spark. This increase in gap distance is possible because of the heating of the electrodes by the current flow, which is concentrated within a decreasing area on the electrodes as they separate. This, in turn, causes the emission of electrons due to the rise in temperature in the smaller conducting area of the electrode. Sparking will continue until the gap dimension has increased to a point where the gap resistance no longer permits sufficient current flow to maintain electron emission temperature at the surface of the electrodes. Thus, the ionization between the electrodes ceases because of decreased electron current flow, and the spark is extinguished.

It should be noted that when a parallel-resonant tuned circuit is placed across the electrodes of a gap in an electromagnetic field, sparks are more easily produced because of a resonant rise in voltage across the tuned circuit, which is tuned to the applied frequency. Therefore, it is conceivable that at some frequency the bonding or grounding wire used to dissipate static electricity during refueling operations may actually be resonant at the transmitted frequency (or a harmonic thereof). Note that a half-wavelength in free space for frequencies of 3 MHz and 30 MHz is 164 feet and 16.4 feet, respectively, while a half-wavelength at frequencies of 300 MHz and 3000 MHz is only 19.68 inches and 1.97 inches, respectively. Although the parts connected by the bonding or grounding wire are at the same static or DC potential, these parts are connected by a length of wire, which may represent a relatively high impedance to radio frequencies. Thus. these parts are in effect virtual electrodes of a spark gap, and when an electromagnetic field is present a relatively high RF voltage may be developed between them. Thus, if the gap dimension is sufficiently small, a spark may be produced by breakdown of the vapor-air dielectric between the electrodes of the gap, and ignition of flammable vapors can occur.

d. Summary. The three requirements for the inadvertent ignition of fuel by RF energy are:

(1) The presence of a proper air-fuel mixture.

(2) A correctly-sized gap across which the spark occurs.

(3) Sufficient spark energy and time duration.

Based on the necessity for the simultaneous occurrence of all three conditions, it may be stated that the statistical probability of inadvertent ignition is small.

Handling of aviation gasoline under normal operating conditions does not produce a flammable atmosphere except close to aircraft fuel vents, open fuel inlets during over-the-wing fueling, or close to spilled gasoline.

Note, however, that the vapor densities of aviation fuels are such that released vapors, particularly under calm wind conditions, may travel considerable distances along the ground and collect in depressions where they may not readily dissipate. The concentration of fuel vapors in the area surrounding the aircraft depends upon wind velocity and rate of fueling. Fuel spillage, therefore, represents the greatest hazard.

Although energy from radar or other RF generating equipment represents a potential source of ignition, the greatest hazards to fuels are probably from lightning and the accumulation of static electricity. Protection criteria for these sources is given in NAVAIR 06-5-502, T.O. 31-10-24, NAVSHIPS 0900-005-8000, and in National Fire Protection Association (NFPA) Standard No. 407.

5.2.4 Hazards to Ordnance

a. General. Hazards to ordnance from electromagnetic energy stem from the use of sensitive, electrically-initiated explosive elements, known as electroexplosive devices (EED's), which can be activated by electromagnetic energy, and from the susceptibility characteristics of the equipment used to fire the EED. Hazards include both inadvertent initiation of the EED and degradation of the intended performance characteristics (although, strictly speaking, this is not a direct hazard). Refer to NAVORD OP-3565/NAVAIR 16-1-529.

b. Coupling Mechanisms. RF energy coupling to an EED occurs through the basic mechanisms described in paragraph 5.1.2: by conduction, by radiation, or through a combination of these.

The exterior of a weapon may be energized either by incident fields from external sources or by direct coupling from its own internal sources. Whatever the source, the surface distribution of current and charge may exhibit stationary patterns depending on the method of excitation, the wavelength of the excitation current, and the geometry of the weapon. These patterns are,in general,very complicated.

In electrical and mechanical form, the receiving antennas that contribute to the problem in actual weapons systems are not necessarily recognizable as antennas. They may take the forms of umbilical cables, access doors and hatches, or discontinuities in weapon skins and shields, but they nevertheless function as linear antennas, current loops, or cavity and slot aperture antennas.

Some of the ways in which umbilical cables, apertures, and discontinuities in the weapon skin can function as receiving antennas for RF energy are shown in figure 5-9. Panel (a) of the figure illustrates an umbilical cable as the receiving antenna (vertical or loop) and an internal loop antenna consisting of an EED and its associated wiring. External cables can act as effective receiving antennas when exposed to RF energy, permitting the transfer of RF currents into the weapon, and direct or inductive coupling to an EED bridge wire can result. This type of receiving antenna can be an effective receiver at communications frequencies, depending on the length of the external cables and their connections.

Panels (b) and (c) of the figure illustrate apertures in a weapon skin acting as receiving antennas. These apertures are effective receiving antennas at frequencies at which their dimensions approach one wavelength. The amount of RF energy transferred into the cavity becomes more pronounced when the dimensions of the cavity approach one wavelength. This occurs most often at radar frequencies. The RF energy is coupled from the fields developed in the cavity to the bridge wire by capacitive and inductive means.

Panel (d) illustrates energy transfer occurring as a result of an RF arc. When connection is either made or broken between any two weapon elements having different RF potentials (e.g., connectors between weapon and launcher or between weapon and test equipment), arcs occur which can produce large amounts of energy in the DC and audio frequency ranges. If RF arcs occur in the firing circuits and there is a complete DC circuit, this energy can be delivered to an EED even if the EED is protected by a low-pass filter.

Under any of the conditions illustrated in figure 5-9 the energy transfer can be increased by personnel in proximity to the weapon. The human body displays receiving antenna characteristics, and the addition of personnel can increase the efficiency of the transfer path of RF energy to the susceptible portions of the weapon.

c. Susceptibility Characteristics. Electroexplosive devices (EED's) are used in virtually every major piece of naval ordnance. They take a large number of different configurations and have many applications (see table 5-5), but their essential nature remains the same.

By accepted definition, an EED is an electric initiator or other component in which electrical energy is used to cause initiation of explosives contained therein. Inadvertent initiation of an EED may occur as a result of RF energy unintentionally conducted to the EED. This is the basic problem. The designer is reminded of the Navy requirement that an EED should be used only when the system requirements cannot be met by other means which are equally effective.

A schematic diagram of the most commonly used type of EED (hot bridge wire EED) is shown in figure 5-10A. An EED of this type is normally initiated by passing a direct current through the bridge wire, heating it, and thus initiating the primary explosive charge surrounding it. The primary charge sets off the booster charge, which in turn sets off the main charge. Although some types of EED's are initiated by arcing or shock waves, heat is the most commonly used method of initiation. Radio frequency energy can initiate or dud an EED in the same manner, i.e., by resistance heating of the bridge wire.

Table 5-5. Typical Application of EED

Category	Application
Rocket Ordnance	Ignition systems for solid and liquid propellent
	Explosive actuation of battery systems
	Explosive mechanical detents
	Detonators for warheads
Guided Missiles	Ignition systems for solid and liquid propellents
	Explosive actuation of relays, switches, and valves
	Self-destruct systems
	Power for electric generators
	Power for gyroscopic guidance systems
	Power for control surfaces
	Separation of nose cones
	Inflation of flotation bags for recovery systems
	Detonators for warheads
Aircraft	Jettison of wing tanks, pods, and cargo
	Ejection of bombs, seats, rockets, and canopies
	Launching of aircraft, rockets and missiles
	Actuation of emergency hydraulic systems
	Starter units for jet engines
	Fuzes for bombs, rockets, and missiles
Shipboard	Primers for large guns
	Fuzes and charges for mines, depth charges, and torpedos

The adverse effects of RF excitation are not confined to accidental initiation. Heat generated by RF energy in the area of the bridge wire, even though it may be insufficient to ignite the primary explosive, can appreciably reduce its sensitivity. If continued over a period of time, this heat can render the primary mix so insensitive that the EED cannot be fired. This hazard, called "dudding," is as undesirable (from a reliability standpoint) as inadvertent initiation.

In pulsed RF environments, there occurs a phenomenon called "thermal stacking" which can increase the likelihood of inadvertent initiation or dudding. The heat generated by a single pulse of energy may be insufficient to initiate the EED; but if the time between pulses will not permit the bridge wire to cool, successive pulses can progressively elevate the bridge wire temperature until the initiation temperature is reached. Figure 5-10C, in which the heat increase is shown graphically, demonstrates that the temperature will rise from the ambient level until it reaches a final equilibrium point, after which no further increases will occur. This final temperature, which is a function of pulse amplitude, duration, repetition rate (duty cycle), and the thermal time constant, may be sufficiently high to cause dudding or even to initiate the EED. In considering the hazard in pulsed environments, the effects of thermal stacking must be considered.

There are two modes of RF excitation of an EED: the differential mode and the coaxial mode. In the differential mode, the two-wire line is balanced and the RF energy propagates to the EED between the two wires in the same manner as the normal DC firing current. This will cause joule (resistance) heating of the bridge wire. Figure 5-10B illustrates the differential mode of excitation. The coaxial mode of RF excitation is most obvious

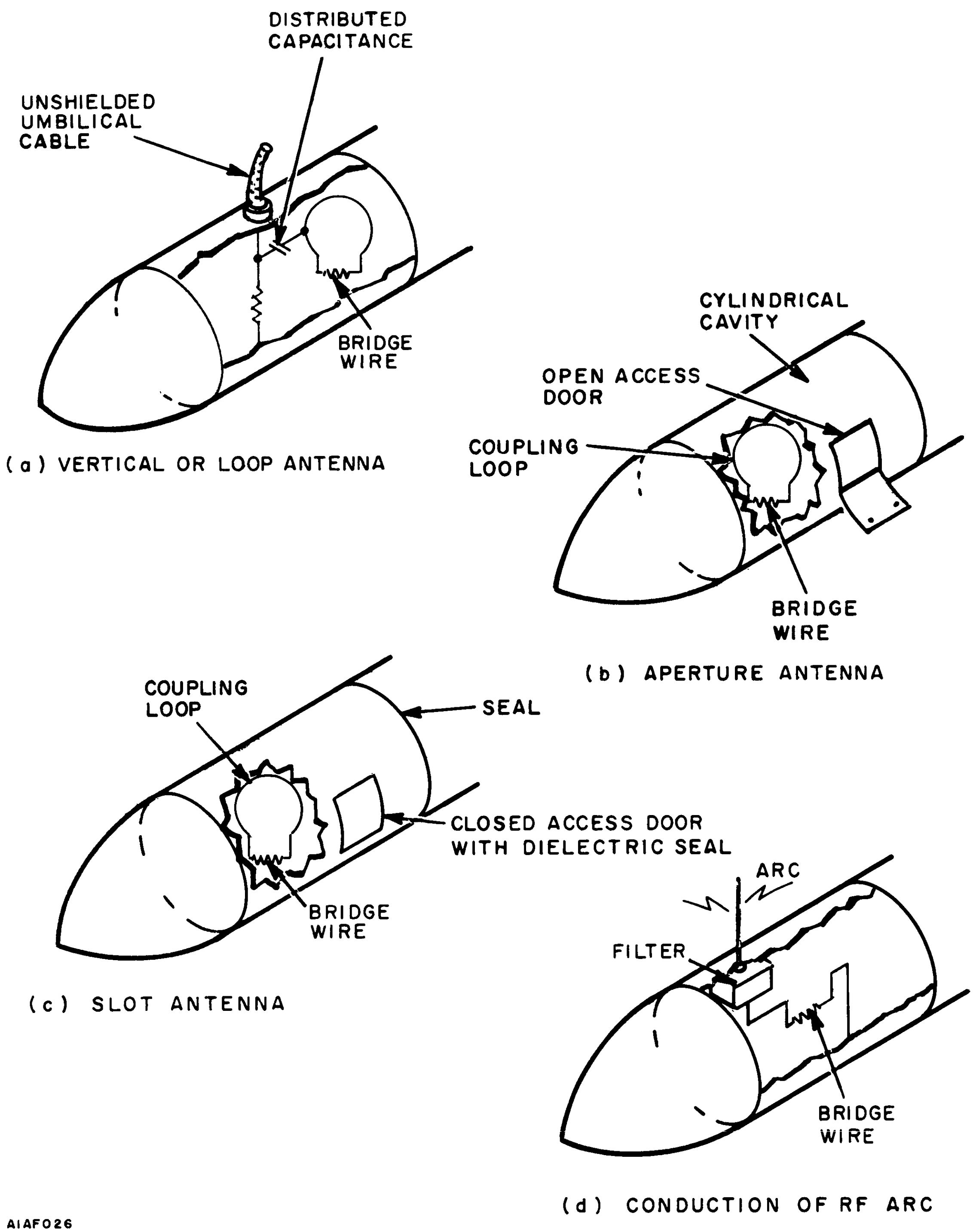

Figure 5-9. Methods of Coupling RF Energy into a Weapon

in coaxial type firing systems. Even though a two-pole balanced shielded system is used, however, a coaxial mode of excitation can be established from any break or high impedance connection in the shield continuity. Such a break is shown in figure 5-10D. The impedance (Z) is the return path through all preceding circuitry. The coaxial mode of excitation causes a high RF potential to be developed from the bridge wire through the explosive mix to the EED case.

In the differential mode of excitation, it might appear that if a large mismatch of impedance between the EED and the transmission line occurs, it would be difficult to effect a transfer of energy to the EED. It should be remembered, however, that although these impedance mismatches may exist, there is often sufficient energy available to induce hazardous amounts of current in the EED. In addition, the RF impedance of an EED differs considerably from its DC resistance, and it would be difficult to determine an EED's RF impedance under all conditions of application.

d. Information on hazards to electric blasting caps may be found in ANSI C-95.4, Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps.

5.2.5 RADHAZ to Equipment

a. General. Electromagnetic radiation of high-enough levels can cause physical, permanent damage to C-E equipments. The interaction of electromagnetic fields with dielectric materials is generally characterized by thermal heating, resulting in an increased "heat stress" of the material, while the interaction of X-radiation and materials is generally characterized by ionization of the atoms, resulting in possible changes in the molecular structure of the material. Since inadvertently emitted X-rays are usually confined to a small region surrounding the source, hazards to equipments from X-rays have a small probability of occurrence. Greatest emphasis, therefore, is placed upon the effects of electromagnetic energy upon equipment.

b. Electromagnetic Pulse. In recent years, work has been done on the effects of nuclear blast generated electromagnetic pulses (EMP). The electric and magnetic fields generated by a nuclear explosion can damage the sensitive equipment in use today. Basically, EMP has three transient effects: a pulse of ground current that flows radially from the point of explosion; a magnetic field pulse that propagates away from the point of explosion with the same vector components as from a vertical dipole; and a corresponding pulse of electric field. Each of these effects can cause damage to equipment, some examples of which follow.

o Ground Current Damage. Buried communication or other cables may be damaged through rupture of insulation or crushed sheathing. An induced voltage pulse can travel down the cable conductors and damage associated equipment.

o Magnetic Field Damage. Peak flux and rate of change of flux may be of sufficient magnitude to destroy magnetic memories, induce high voltages in wiring with associated possible damage.

o Electric Field Damage. Induced voltage or current transients on high impedance, unshielded or unbalanced wiring may damage components of high susceptibility.

Detailed information on EMP effects and protective practices may be found in DASA Electromagnetic Pulse Handbook 2114, Office of Civil Defense document TR-GIA, and Oak Ridge National Labs document ORNL-TM-2830.

c. Solid State Damage. The mechanisms leading to damage to equipment from electromagnetic energy are complex. Damage commonly occurs at the circuit component level, i.e., transistor, diode, etc., and is a function of the type, level, and duration of exposure, the components or parts exposed, the nature of the electromagnetic field, and many other factors. Damage may occur from direct exposure to radiation via thermal heating or, more probably, from voltages or currents induced by electromagnetic fields at antenna terminals, circuit wiring, component terminals, power lines, etc.

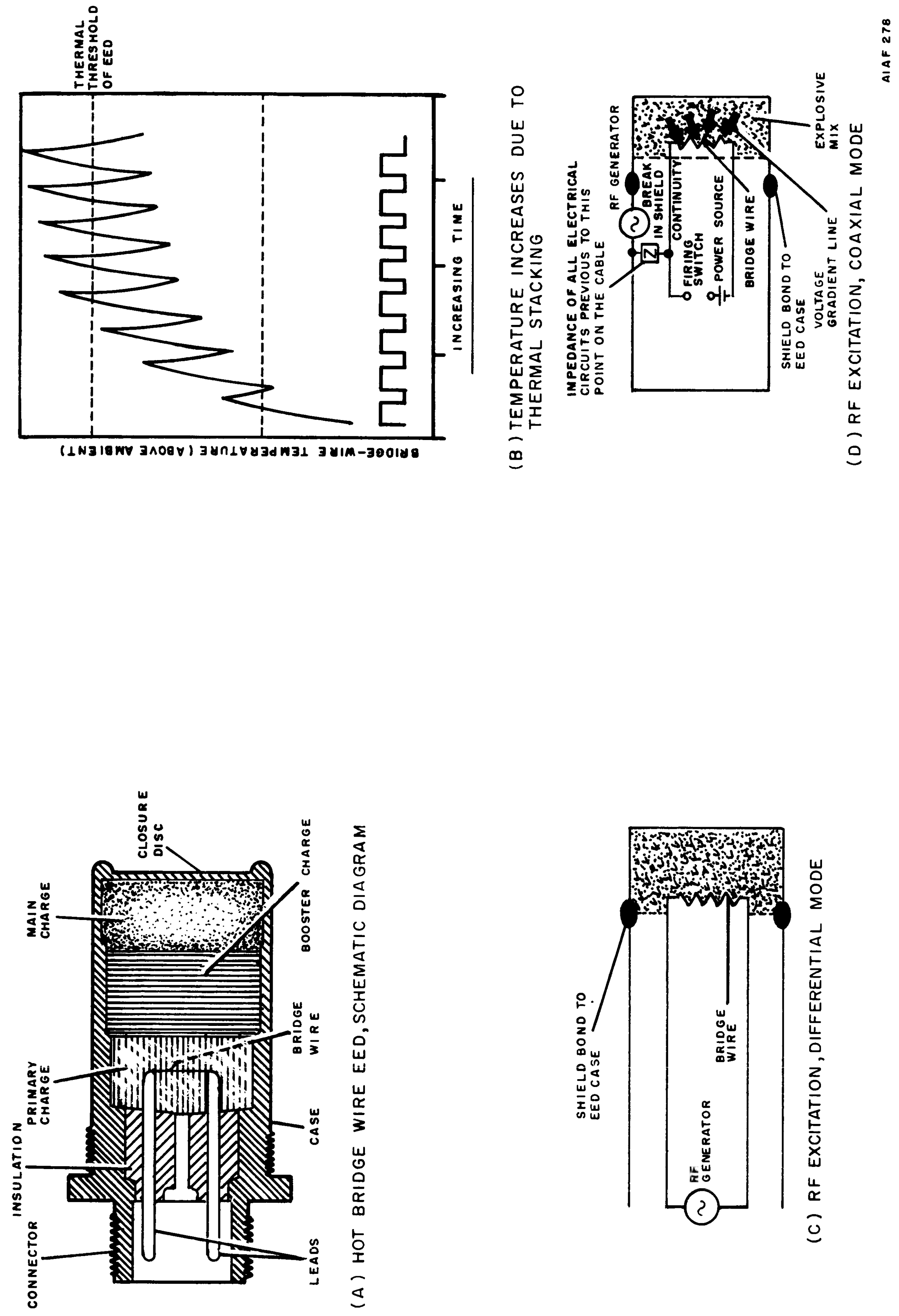

Figure 5 - 10. Various Types of RF Excitation of an Electro-Explosive Device

Solid state circuitry is especially susceptible to peak levels and to rate of change of voltages and currents. Data on semiconductor burnout, for example, indicates that a range of 10^{-4} to 10^{-6} joules represents the threshold for semiconductor damage and possible subsequent equipment damage. Since burnout can occur in microseconds, even momentary exposure such as may occur from rotating or scanning antennas. represents a potential hazard.

In addition, arcing or corona caused by induced high voltages can damage relay terminals, antenna couplers and other components.

A knowledge of both the transient behavior and electromagnetic susceptibility characteristics of electronic parts is therefore necessary in order to select and apply optimum protective methods for C-E equipments.

Transistors and other semiconductors, including integrated circuits (microelectronics), are especially susceptible to damage from fast transients where peak-induced voltages exceed the maximum ratings of the device. The effects may be temperature sensitive, as in silicon devices where reverse breakdown voltage decreases with increasing temperatures. Since most transistors have an emitter-base reverse breakdown voltage of from 1 to 5 volts, it can be seen that they may be easily damaged. Voltage spikes can cause a build-up of impurities concentrated at a point in the collector and emitter junctions which can result in punch-through or internal shorting of the transistor at a later time. Both transistors and diodes operating in an electromagnetic field can absorb sufficient energy to cause the junction temperature to be exceeded, which may result in partial damage or total destruction. This is especially true if the device is operating at or near its rated junction temperature. Diodes are also subject to reverse breakdown by induced RF voltage in excess of the device rating. SCR's and other four-layer devices are sensitive to rate of change of forward voltages, as well as peak reverse voltages.

d. Medical Electronics Consideration. Recent investigations have shown that medical devices, such as cardiac pacemakers, hearing aids, and artificial limbs are susceptible to electromagnetic fields. For example, in the case of pacemakers, experiments with RF transmitters have demonstrated the possibility of inhibiting the production of pulses required for the pacing of the heart.

Damage to pacemakers, or even temporary inhibition of operation, can result in death. In the absence of definitive criteria as to hazardous levels and frequencies, it is best to prevent personnel using such medical devices from being exposed to RF radiation of any level.

5.2.6 Hazard Sources

Some of the major sources of electromagnetic hazards are; the intended fields emitted from radar and communications antennas, especially those types which concentrate electromagnetic energy into directed beams, extraneous radiations from cables and structures, and the unintended X-radiation from any device in which voltage levels exceed approximately 10kV, especially microwave and other electron tubes or devices using high plate voltages.

a. Antennas. Antennas may be grouped into two general classes: omnidirectional and directional. As their name implies, omnidirectional antennas radiate energy in all directions simultaneously. They are used chiefly in mobile communications, broadcasting sources, IFF (Identification, Friend or Foe), and similar equipment where broad area coverage is required. The omnidirectional antenna rarely presents a hazard problem (at least to personnel) for two reasons: its emitted energy is so spread out that power densities seldom reach hazardous proportion (a notable exception to this is the case of the region immediately surrounding a very high power broadcast antenna), and the operating frequencies used are not absorbed by the body. Directional antennas, on the other hand, radiate energy in relatively narrow lobes or beams that extend out from the antenna in one or, at most, a few directions. They are used for transmission between two fixed points, as in HF communications, microwave relays, etc., and for the many types of radar in use today. Because of their directional characteristics, i.e., the concentration of electromagnetic energy into narrow beams, and because of their use at extremely high powers, this category of antenna forms the major source of hazardous electromagnetic fields.

b. Electromagnetic Environment. For the purpose of describing the electromagnetic field or environment at a particular site, antennas may be grouped into classes according to the ratio of the antenna physical size to the wavelength of the radiated energy. Antennas are classed as large radiators when this ratio is much greater than unity, and as small radiators when of the order of, or less than, unity. Radar antennas are most frequently of the former class.

The field produced by an antenna may be partitioned into two distinct regions called the near field and the far field, as discussed in paragraph 5.1.2. For large radiators, that portion of the near field beginning one wavelength from the antenna (usually only a few centimeters for radar antennas) and extending to approximately $2D^2/\lambda$ where D equals the antenna diameter or maximum dimension, and λ equals the wavelength, is called the Fresnel region. The far field, or Fraunhofer region, begins at the approximate end of the Fresnel Zone, and extends to infinity. In actuality the ending of the Fresnel Zone and the beginning of the far field region is not a distinct line of demarcation, but rather a "cross-over" or transitional region exhibiting combined properties.

In the Fresnel region the radiated beam may be considered collimated, having a cross-section approximately equal to the projected area of the antenna aperture. The power along the axis of the beam is highly concentrated in this region because of the effects of the reflector. Since the beam is being formed in this region, the energy distribution across the beam is not uniform and both antenna gain and beamwidth vary with distance from the antenna. The above characteristics are also dependent upon the type of antenna illumination. This refers to the tapering of the energy distribution across the aperture, according to various mathematical relationships, in order to reduce the emitted sidelobes. A 10 dB taper from center to edge is usually employed, with maximum energy occurring at the center.

Beyond the Fresnel region, the radiated beam begins to spread out in a conical pattern until that region is reached in which the radiated energy may be considered to exist as uniform plane waves, and the power density along the axis decreases according to the inverse square law. This is the Fraunhofer or far field zone. Figure 5-11 depicts the various regions of a large aperture antenna.

(1) Power Densities In a Typical Radar System. Significantly different levels of electromagnetic energy exist in each radar system. In the typical radar system shown in figure 5-12, the highest power density exists within the waveguide which normally is closed and therefore not readily accessible. Power density, expressed in terms of average watts per square centimeter, is given approximately by the equation:

$$W \approx \frac{P}{A_t} \tag{5-2}$$

where:

W = power density, in average watts/cm^2

P = average power output of transmitter, in watts

A_t = cross-sectional area of transmission line, in cm^2

It should be noted that the power is not distributed uniformly over the entire area of the waveguide as implied by the equation 5-2 but the equation gives a close approximation.

The waveguide conveys the power to an antenna feed, which in turn feeds the energy on to the antenna. Before reaching the antenna, the energy from the feed is propagated through space which ordinarily is not enclosed, and is therefore more accessible to personnel than is the inside of the transmission line. The power density in the aperture of the feed is given, again approximately, by the equation in the preceding paragraph, except that the feed aperture A_f is now used instead of A_t. Since the feed aperture, A_f, is usually larger than the cross-sectional area of the waveguide A_t, the power density in the feed aperture is usually less than that in the line.

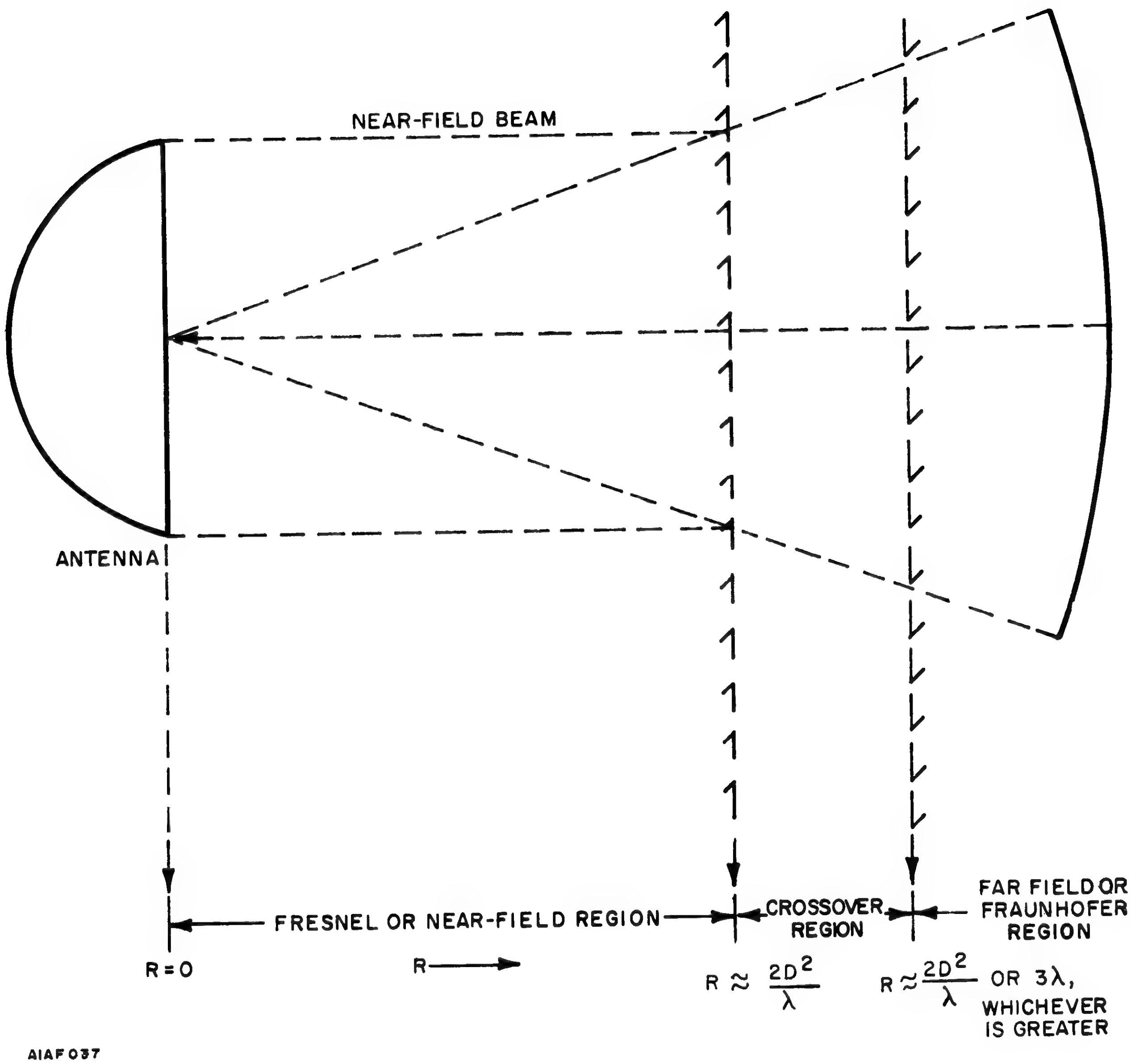

Figure 5 - 11. Antenna Radiation Region

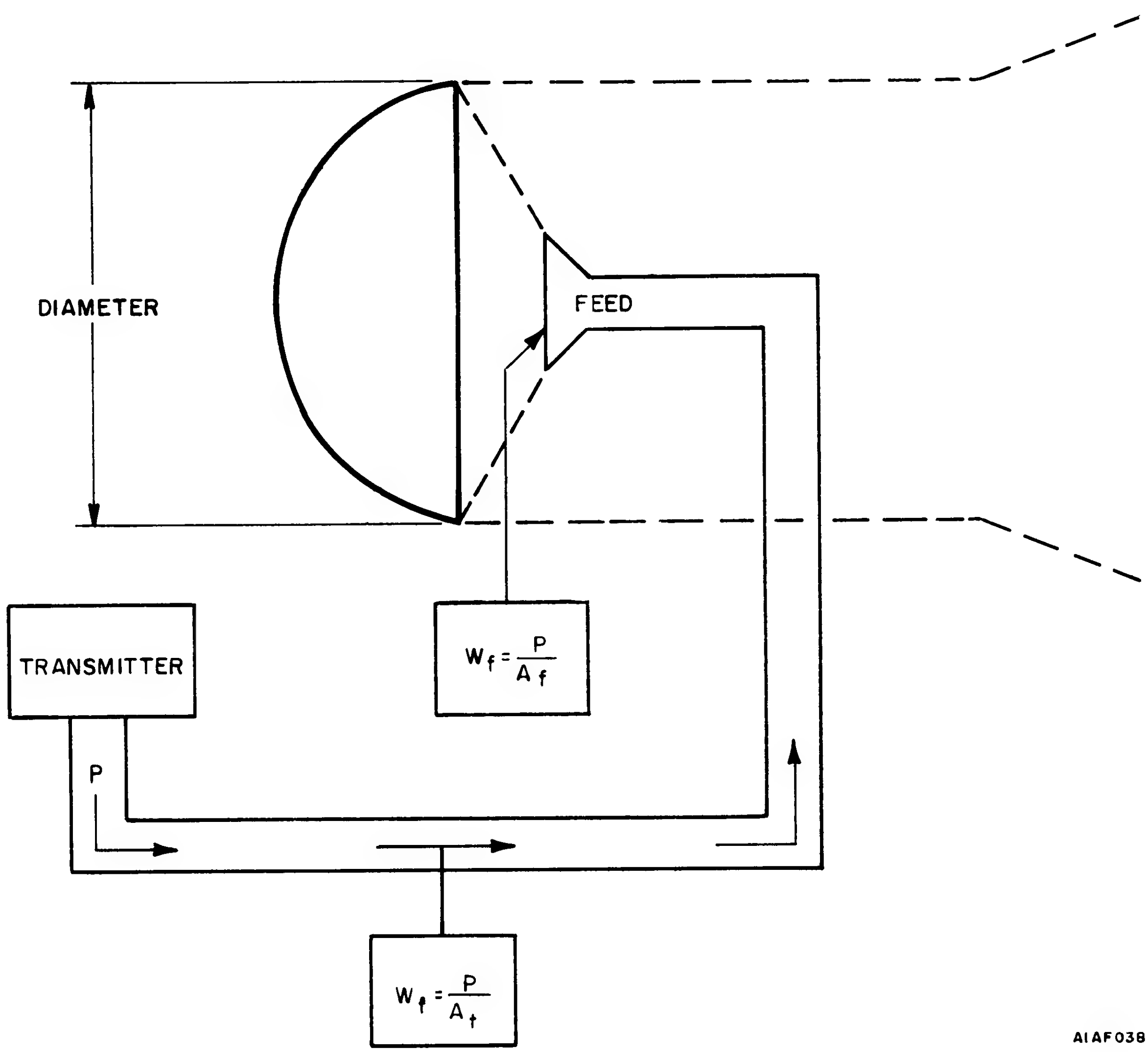

Figure 5 - 12. Typical Radar System Power Densities

From the antenna, the electromagnetic energy is radiated into free space. While the energy is travelling through space, it cannot be controlled. This fact constitutes one of the biggest problems in combatting possible hazards of this radiation.

The manner in which the radiated energy is emitted and interacts with the environment is complex and subject to many variations. Propagation of the emitted energy may be via ground waves, sky waves, or a combination of both, and is affected by the conductivity of the earth, ionospheric effects, absorption or reflection by obstacles and many other phenomena.

Ground and structural reflections, for example, may add to the main beam causing a value of power density which is four times the free-space value. Thus, fields at the threshold of hazardous levels in the absence of reflections can become hazardous at points where reflection occurs. The direction and type of polarization of the electric field vector also plays a role in determining the nature and extent of interaction between the field and personnel/materials. Analytical methods of determining power density levels of antenna fields are discussed in this handbook.

c. X-Radiation Sources. It is known that the high voltage tubes used in the generation, amplification and shaping processes associated with microwave and radar transmissions are inadvertent producers of X-radiation. Klystrons, magnetrons, travelling wave tubes, crossed-field amplifiers, thyratrons, high voltage rectifiers, CRO's and other tubes are thus sources of potentially hazardous X-rays. Generally, those tubes which operate at anode or accelerating voltages of less than about 15 kV, generate soft X-rays, i.e. low energy rays which usually do not penetrate the tube envelope. Higher voltage tubes, especially those operating under high intensity, low duty cycle pulse conditions, can produce hazardous radiation at distances of several feet from the tube. The energy of the emitted rays are a direct function of the square of the accelerating voltage, the average tube current and the target material atomic number. X-ray energy may increase as a tube ages, or if unstable operating conditions exist. Linear beam devices such as klystrons and travelling-wave tubes generally show greater X-radiation generation with the RF drive applied than with no RF drive. Emission from these devices generally occurs from the collector and electron gun ends, from cathode bushings and RF output windows, and, in the case of some high power devices, through the anode walls. Maximum intensity occurs at the collector assembly and output regions; with RF drive applied, the emission level can reach an average of 800 milliroentgens per hour, an extremely dangerous level.

5.3 HAZARD CRITERIA LEVELS

The presently accepted maximum exposure limits to EMR of various wavelengths for personnel, fuels and ordnance are discussed in the following paragraphs.

5.3.1 Personnel

a. EMR. The personnel limit of 10 mW/cm^2 for continuous exposure was adopted in 1957 by NAVMED. The intermittent exposure criteria of 300 mJ/cm^2 per 30 second exposure period was established for the case of exposure by rotating or scanning type antennas and is derived from the 10 mW/cm^2 figure. This permits higher levels of exposure for shorter periods of time (less than 30 seconds) up to a limit of 100 mW/cm^2 for one second in a 30 second period. Both of these figures are based on present knowledge, with consideration of the tolerable rise in tissue temperature.

b. X-Radiation. The limits given in table 5-6 for X-radiation were established by the Bureau of Medicine and Surgery. They are based on long experience with man working in a known radiation environment and reflect those dose levels which, in the light of present knowledge, will not cause appreciable injury to an average individual at any time during his normal life span. As additional knowledge is gained concerning the biological effects of X-Radiation, particularly for low-level exposures, the values listed are subject to revision.

c. Tables 5-7 and 5-8 present the maximum exposure limits established by NAVMED. Additional information may be found in NAVMED P-5055.

5.3.2 Fuels

The "safe" limit of exposure for fueling operations and fuel storage area is based on present "highly limited" knowledge of minimum voltage required for arcing and has not been generally accepted as the definitive criteria. The complete characterization of hazards to fuels probably requires that a complex, worst case, formula be developed which relates the parameters of fuel flammability limits, minimum gap spacing, and spark energy-time dependence. Due to the complexity of the variables that must be defined, development of this formula is prohibitive.

However, in assessing and reviewing the hazardous characteristics of fuels, the following information must be considered relative to energy and duration of arc, and gap distance.

o From actual measurements of voltages and currents on aircraft located on a carrier deck near an energized antenna, a volt-ampere product of fifty or more was required to ignite gasoline vapor in a test device. It should also be noted, however, that only 120 volts is necessary to draw an arc (that is, touch two electrodes and then separate) and that inductive surges energized by low voltage sources can yield sufficient voltage to produce sparks.

5.3.3 Ordnance

The levels for Ordnance are given in MIL-P-24014 as the environmental field levels to be used in the design of weapon systems to preclude spurious functioning or degradation of any EED. Figures 5-13 through 5-16 present currently accepted safe limits, as given in MIL-P-24014.* When evaluating hazardous situations relative to ordnance, to obtain details in the process refer to NAVMATINST 8020.1C, NAVELEXINST 5100.4, and NAVFAC 8020.2 and 8020.3 series regarding responsibilities.

Table 5-6. X-Radiation - Maximum Limits For Personnel

TYPE OF EXPOSURE	PERIOD OF EXPOSURE	DOSE IN REM WHICH SHOULD NOT BE EXCEEDED	NOTES
Whole body, head and trunk, active bloodforming organs, gonads or lens of the eye.	Calendar quarter Permissible accumulated dose after 18th birthday.	3 5 (n-18) where n=age in years	Total life-time dose
Skin of whole body, or thyroid	Calendar quarter Year	10 30	
Hands and forearms, or feet and ankles	Calendar quarter Year	25 75	

* For current information, use latest issue of MIL-P-24014.

Table 5-7. Laser Radiation - Maximum Limits

CATEGORY	ABSOLUTE MAXIMUM LIMITS - 0.4 TO 1.4μ*			10.6μ CO_2
	Q-SWITCHED †	NON Q-SWITCHED	CONTINOUS	
Personnel Eye (Corneal Incidence)	5-50 ns Pulse width 10^{-7} J/cm^2	1.0 ms width 10^{-6} J/cm^2	10^{-6} W/cm^2	100 mW/cm^2
Skin	10^{-2} J/cm^2	10^{-1} J/cm^2	10^{-1} W/cm^2	100 mW/cm^2

*NOTE:

a) Safety factor of 2 recommended for field evaluation and training activities, excluding CO_2 laser.

b) Safety factor of 10 recommended for long term laboratory use, excluding CO_2 lasers.

† Q- Switching or Q- Spoiling refers to the operation of a laser in a pulsed mode to obtain high peak power of short duration.

Table 5-8. Laser Radiation- Maximum Allowable Limits

RADIANT INTENSITY FROM A DIFFUSE SURFACE REFLECTION AS MEASURED AT THE REFLECTING SURFACE		
Q-SWITCHED	NON Q-SWITCHED	CONTINUOUS
0.07 J/cm^2	0.9 J/cm^2	2.5 W/cm^2

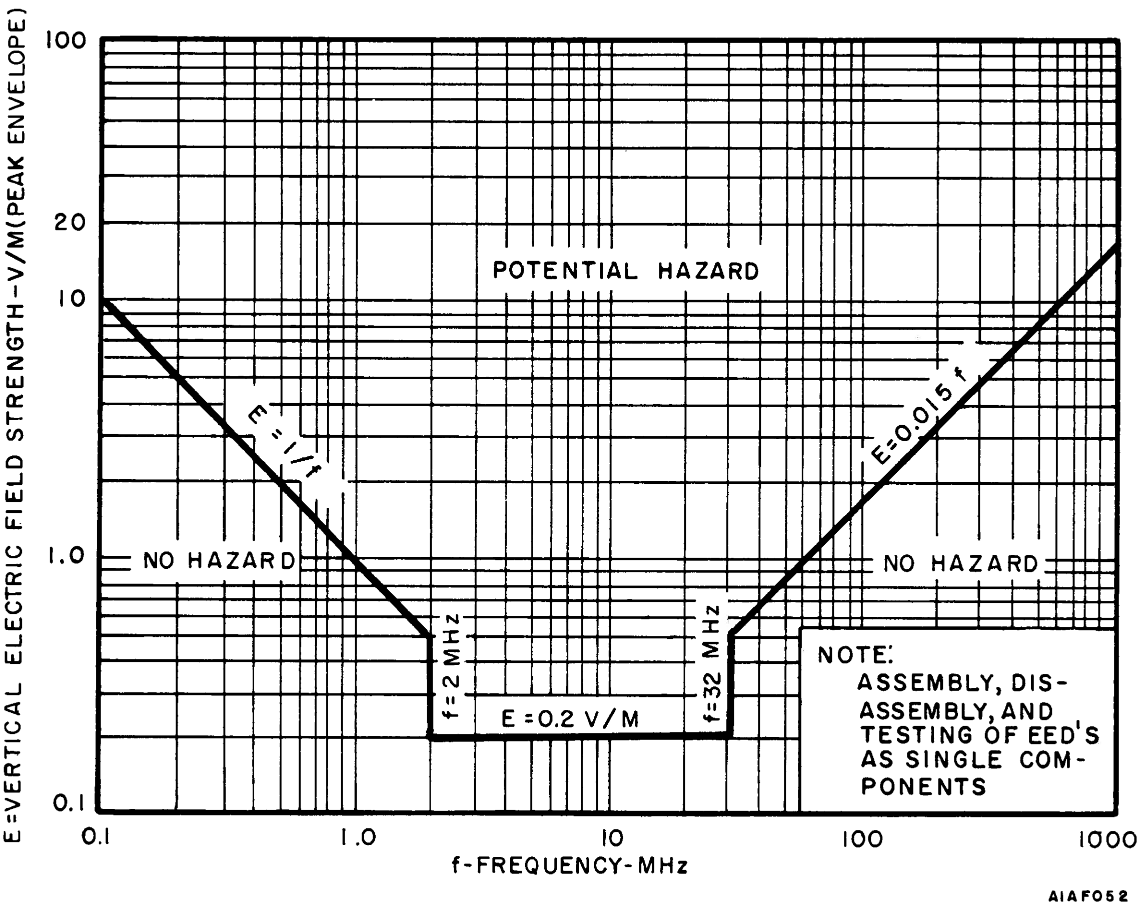

Figure 5 - 13. RF Field-Intensity Potentially Hazardous to Ordnance In Optimum Coupling Configurations-Radio Frequencies

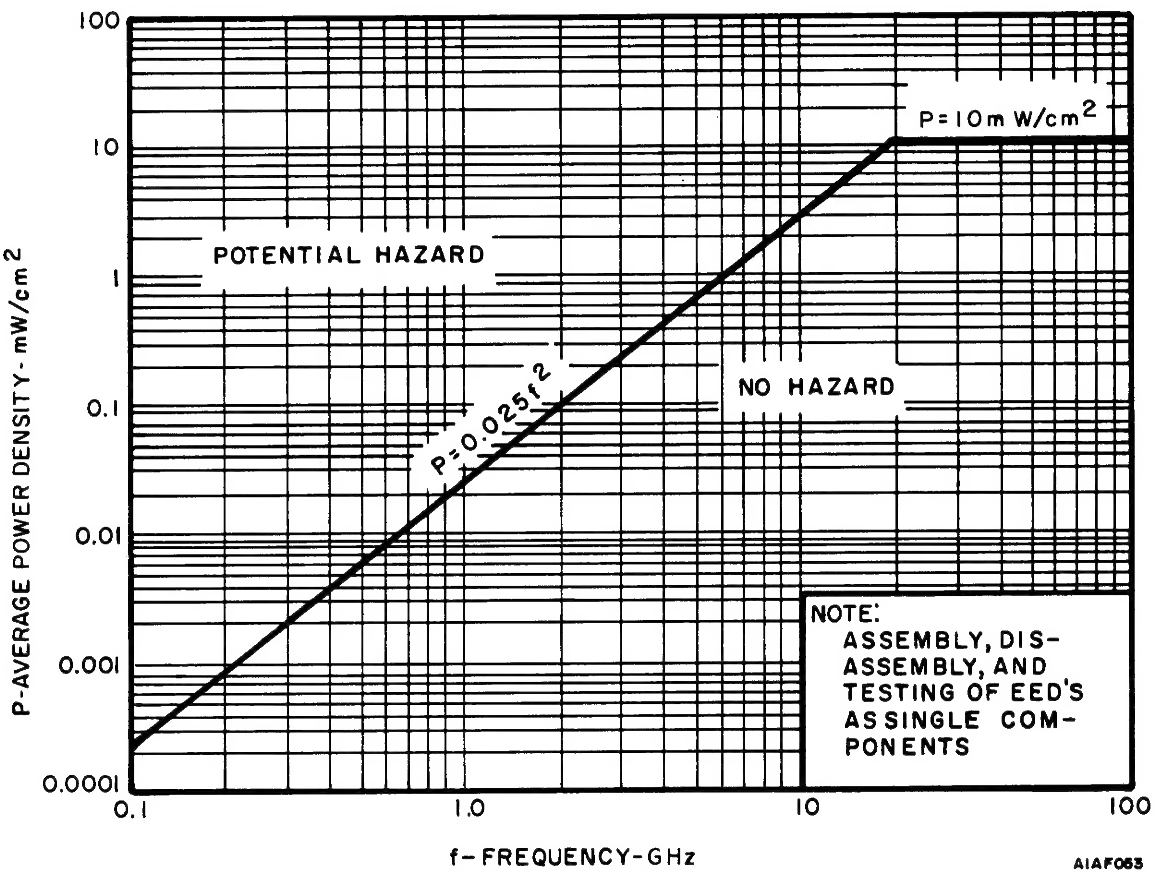

Figure 5 - 14. Radar-Frequency Field-Intensity Potentially Hazardous to Ordnance in Optimum Coupling Configurations

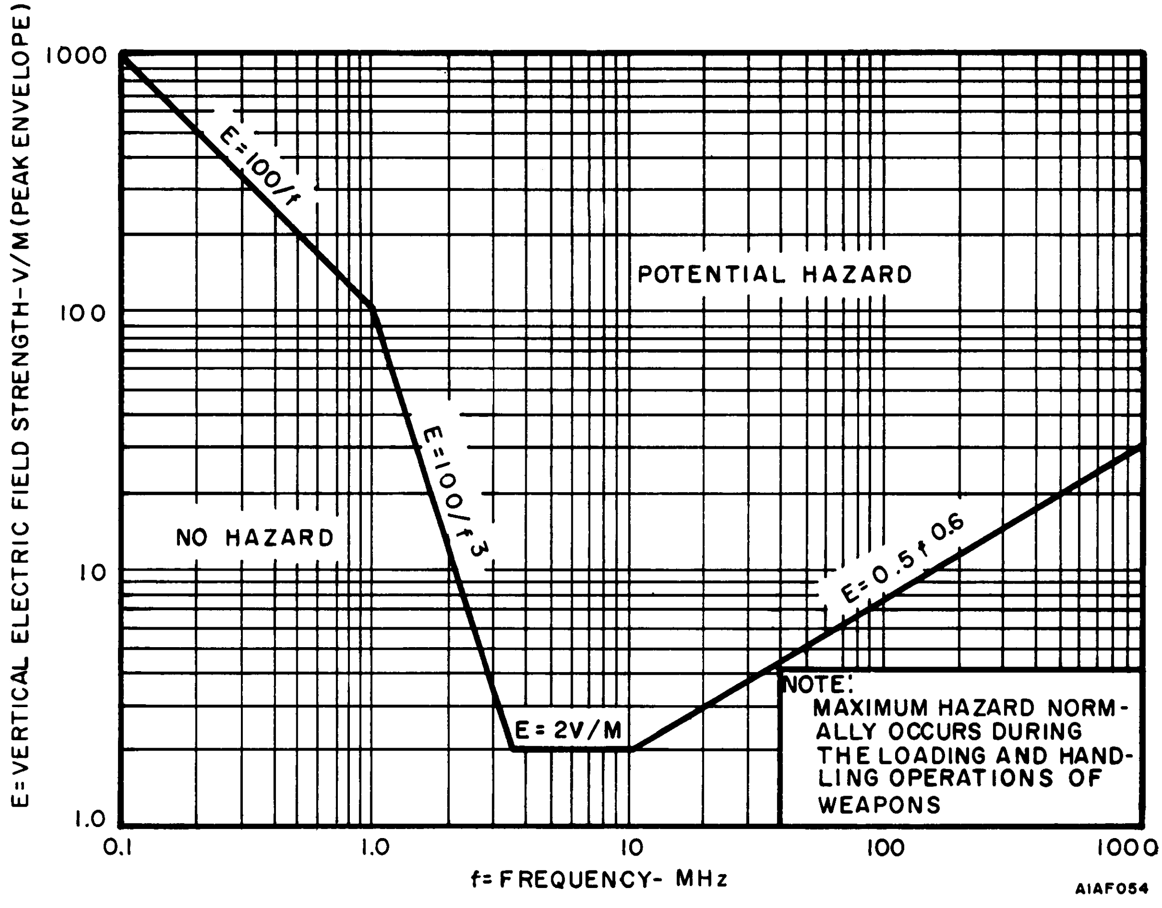

Figure 5 - 15. RF Field-Intensity Potentially Hazardous to Susceptible Weapons Which Require Special Restrictions

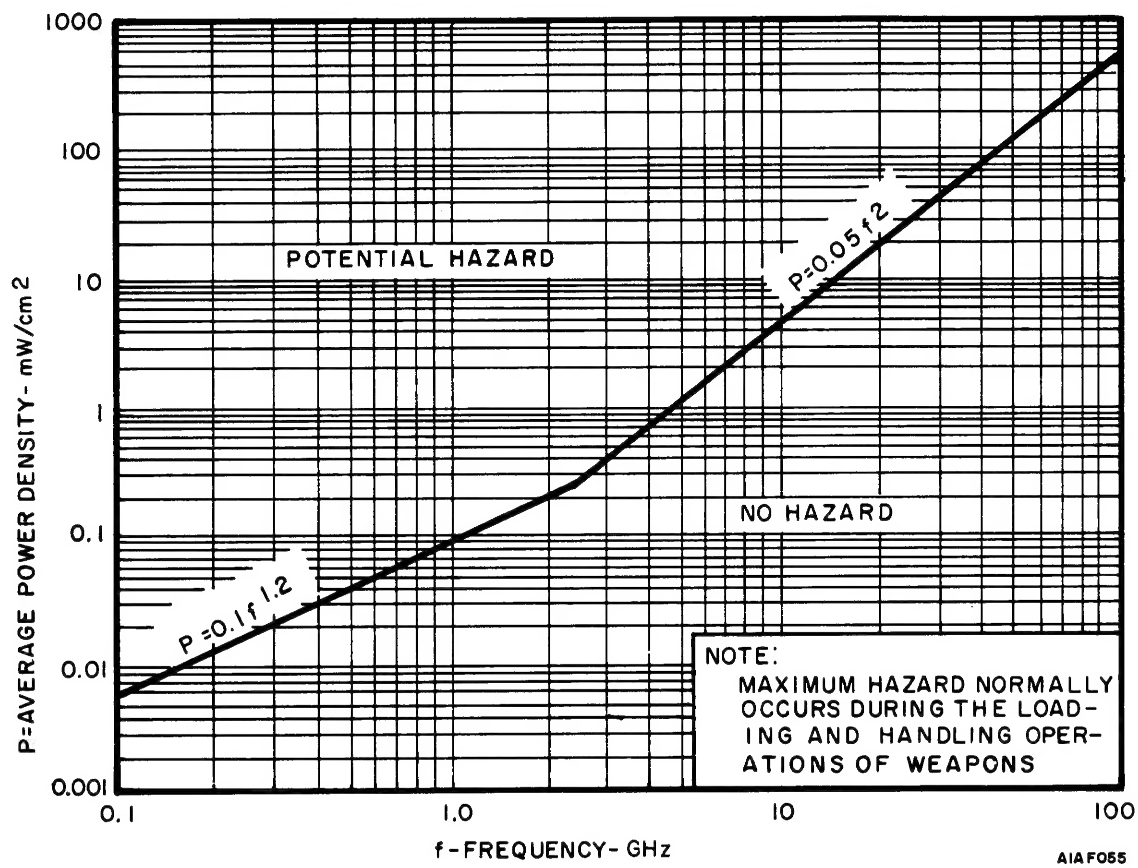

Figure 5 - 16. Radar-Frequency Power Density Potentially Hazardous to Susceptible Weapons Which Require Special Restrictions